ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES, FACULTY OF SCIENCE

DEPARTEMENT OF EARTH SCIENCES

Environmental Analysis of the Areal Expansion and Lake Level Rise of Lake Beseka, Main Ethiopian Rift

Thesis Submitted In Partial Fulfillment of the Requirements for the

Degree of MASTER OF SCIENCE in Geo-Environmental Systems Analysis

By

Fassika Abebe Beyene

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Approved by board of examiners

Dr. Balemual Atnafu ______________________

(Chairman, Department Graduate Committee)

Dr. Asfawossen Asrat ______________________

(Advisor)

Dr. Bekele Abebe ______________________

(Examiner)

Dr. Muhamed Umer ______________________

(Examiner)

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ABSTRACT

Lake Beseka has been drastically expanding from its original size of about 3Km^2 (in the year 1964) to its current size of 41 km^2 (in the year 2006) in the last four decades. Equally, the lake level has been rising at an average annual increment rate of 0.28m.

The expansion of the lake has imposed several impacts on the social and natural environment of the surrounding area. The continuing rise of the lake level resulted in inundation of valuable grazing and farmland and watering points. Further rise could result in a complete inundation of the road and railway line passing nearby and substantial amount of the farm and grazing land in the vicinity. The ultimate increase in size of the lake may lead to the spillover of lake water into the river Awash, which due to the highly alkaline and saline nature of the former may affect the hydrochemistry of the river and the ecosystems down stream.

This work addresses the areal expansion and lake level rise of Lake Beseka using an environmental analysis approach where water balance modeling and land use/land cover classifications and change detection analysis were employed.

The water balance modeling revealed that surface water sources are not significant contributors to the lake level rise; rather sub-surface inflow, which includes spring discharges and deep groundwater sources are significantly affecting the lake level.

Land use/land cover (LU/LC) change detection between the years 1973 and 1986 and between 1986 and 2003 were conducted, with the objective of creation of historical and current LU/LC maps and LU/LC change map of 1973, 1986 and 2003. The maps were derived utilizing standardized digital remote sensing classification techniques using three multi temporal Land sat scenes acquired on January 12, 1973 (MSS), January 28, 1986 (TM), and January 27, 2003 (ETM+).

The change detection analysis revealed that the lake body has increased by 21.82 km^2 (301.301%) between 1973 and 1986, and by 9.86 km^2 (33.938%) between 1986 and 2003. Between 1973 and 2003, the lake has expanded by about 31.68 km^2 (335%).

The land use/land cover of the area significantly changed in the last three decades. This change has a direct effect on the expansion of the lake. Vegetation cover (shrub land) had been reduced by 65.41 km^2 (30%). This in turn affects the runoff yielded from the catchment entering in to the lake. Unlike vegetation cover, degraded land had increased by 33.28 km^2 (89.575%), which increases runoff entering in to the lake. Irrigation farmland which increased by about 13.63 km^2 (5 7.411%). Water for irrigation is brought from Awash River that in turn is an input to the inflow of the lake; this has a great effect on areal expansion of the lake. The above result indicated that the land use/land cover change of the area has an additive effect on the lake's areal expansion.

LU/LC changes in the area are still intensified due to areal expansion of the Lake, population pressure, and unwise intervention of man with the environment (including unsatisfactory Irrigation Practices). Conservation of the natural resource, rehabilitation and management of the environment through land terracing and vegetating with productive plants are the envisage possible strategies that have to be taken to combat the existing and future adverse LU/LC changes that are associated with areal expansion of the Lake.

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Lakes situated in the Main Ethiopian Rift Valley are affected by climatic changes, such as rainfall and its seasonality, which might change on a regional or global scale. Their hydrological regime is also strongly influenced by the geologic phenomena characterized by rifting and associated magmatism and sedimentation. However, effects of non-climatic factors induced by human-induced activities might exceed climate-change driven effects on lake level (Goerner, A., 2005).

Lake Beseka is located at about 195 km east of Addis Ababa, in the Main Ethiopian Rift (MER), near Metehara town, at about 955 meter above sea level, at the foot of Mount Fentale. The mean annual rainfall is about 540 mm and monthly temperature varies from 21^{o}C to 28^{o}C. In the early 1960s, the surface area of Lake Beseka was only around 3 km^2. In 1976, the lake area was estimated to be 27.5 km^2 and now it covers around 41 km^2 (Alemayehu et al., 2006).

The lake level and areal extent has been more or less constant with minor fluctuations during the wet and dry seasons until the late sixties and early seventies, and has been increasing since then. Formerly the lake was on the southwest side of the main high way and railway lines, joining the capital to the eastern part of the country and Djibouti. Currently the lake has engulfed the lines and covers the area on both sides.

The steady rise of the water level of Lake Beseka, over the past thirty years has required the highway and railway lines to be raised several times. Apart from threatening the existing infrastructures, drastic expansion of the lake has flooded and inundated the adjacent grazing lands and partially inundated Abadir Farm, part of Metehara Sugar Estate, which is located to the southeast of the lake in the vicinity.

The continuous increase of the lake size and the damage experienced has attracted the attention of a number of institutions and governmental organizations, especially that of the Ministry of Water Resources (MoWR), to respond to the challenges.
The results of the study conducted in 1997-98 by the MoWR revealed the following changes in lake level and volume:

- During the years 1964 -1972 (8 years and 5 months), the total change in volume of the lake was about 13.4 Mcm, i.e., the volume of the lake increased at a rate of about 1.7 Mcm/yr and the lake level rose at a rate of about 0.24 m/yr.

- During the years 1972 - 1978 (6 years and 4 months) the total change in lake volume was about 86.6 Mcm, i.e., the lake volume increased at a rate of 13.7 Mcm/yr and the lake level rose at a rate of 0.66 m/yr.

- Between the years 1978 - 1998 (20 years and 8 months) the total change in lake volume was found to be about 129.6 Mcm, i.e., the lake volume increased at a rate of 6.3 Mcm/yr and the lake level rose at a rate of 0.18 m/yr.

The most dramatic period out of 35 years of information was that of 1972 - 1978 which had resulted in abnormal rate of increase in both level and volume of the lake. This could obviously be ascribed to the unsuccessful intervention of the sugar estate in the operation of gates. As it has been revealed by the sharp increase in lake level, in particular in 1977 and 1978, and the increasing trend of inflow due to groundwater sources (including springs) during that period had contributed to some degree for such abrupt increase in lake level and volume.

In light of this condition, one could safely exclude the anomalous period of 1972 -1978, and for a period of 28 years and 8 months, an annual rate of increase at about 0.21m could realistically depict the phenomena in Lake Beseka and said to be statistically uniform trend.

In spite of the fact that most of the remedial measures recommended were implemented in the period 1979 -1983, the lake level and size continued increasing constantly. Therefore, from 1998 to 1999 the Ministry of Water Resources (MoWR) in collaboration with International Atomic Energy Agency (IAEA) carried out intensive investigation, including isotope techniques to determine the cause of the rise and in order to design remedial measures.

The Integrated studies on natural resources in particular, lake water balance modeling, water quality analysis, environmental Isotope studies and groundwater flow modeling resulted in identifying the main cause for the continuous Lake level rise to be the increment of the groundwater discharge flowing to Lake Beseka at the southwest side of the lake.

After determining the main cause of the lake level rise, some remedial measures were proposed. The environmental and socio-economic impact and financial implication of each proposed measure were analyzed, and the necessary remedial measure with least environmental impact and financial implication was recommended and detail designs were made.

All previous studies, on the lake level rise problem, can be categorized into four groups (MoWR, 1997).

- Short field trip reports conducted before 1978 by Awash Valley Development Authority (AVDA) in 1976, State Farm Engineering Department (1977) and Water Resources Development Authority (WRDA) in 1977 (reported in Amharic).

- Inter-Ministerial Technical Committees (IMTC) Study Reports: There are two IMTC studies, which were organized for urgent solutions when the lake level rise threatened to flood the highway, railway and telecommunication lines passing through the lake in 1978 and 1990 reported (in Amharic).

- Direct studies on the rise of Lake Beseka level: There are two studies; the first is the comprehensive study conducted by Halcrow (1978) at a project level as per the recommendation of the first IMTC, and the second, an initial appraisal report by Roofe (1990). The objective of the studies was to identify the main causes of the lake level rise and recommend remedial measures.

- Indirect study reports by NEDECO (1983), MacDonald and Partners (1986): NEDECO (1983) who were employed to reappraise and design the irrigation system of Metehara Sugar Estate considered a diversion of surface water to Awash River in order to alleviate the rise of Lake Beseka level. MacDonald and Partners (1986) who were employed by Sugar Corporation to design irrigation works for the Abadir farm extension considered the possibility of constructing a drain at the limit of the extension area in order to convey all drainage water to the River Awash, possibly by pumping.

Most of the studies have identified that the main cause for the continuous Beseka lake level rise was the unsatisfactory irrigation practices at Abadir Farm. Particularly Halcrow (1978) had concluded that the principal single cause for the lake level rise is the inefficient irrigation practices at Abadir farm and proposed a number of mitigation measures to improve the efficiency of Abadir farm irrigation system. According to the proposals, most of the remedial measures have been implemented from 1978 to 1983. Nonetheless, contrary to the control measures taken the problem continued to persist on with a general trend of continuous lake water level rise.

In spite of all the efforts made by various institutions and organizations, no study have been reported in the literature, regarding environmental systems analysis of the areal expansion and water level rise of Lake Beseka associated with LU/LC changes. Hence, this research is intended to give an integrated environmental resources, LU/LC change detection analysis and assessment methods, which may provide some insight into the future lake level and size increment. The land use/land cover study of the area for such long year (30 years) were not done by many researchers and application of remote sensing and GIS for associated environmental analysis is not common in the area. Hence, this research has put a new result with such new methods of environmental systems analysis. Actually other have done the areal expansion of the lake conventionally(by ground survey) but all the analysis and results of the research is geared with the application of GIS and Remote sensing to replace conventional method by automated once.

1.2 Significance of the study

Systems analysis is a quantitative and multidisciplinary research field aimed at combining, interpreting and communicating knowledge from natural and social sciences and technology. Environmental systems analysis is the application of systems analysis in the environmental field to describe and analyze the causes, mechanisms, effects of, and potential solution for specific environmental problems

This research aims to improve the knowledge of environmental problems through integrated analysis of human activities, their environmental impact and the possible reduction strategies. The substances studied include those associated with areal expansion and lake level rise of Lake Beseka. The current study will contribute significantly in providing information to help predict future conditions of lake level rise and assess the existing environmental problems associated with the lake level rise. It also proposes mitigating measures to be incorporated in the design and operation phases of different investment activities that will be undertaken in the vicinity of the lake. In this regard, this research project is believed to be valuable for decision-makers to use for prediction and management in and around the Lake area.

1.3 Objectives

1.3.1 General objective

The main objective of the study is to assess and analyze the causes and trends of lake level rise and areal expansion of Lake Beseka in order to predict future conditions of the lake.

1.3.2 Specific Objectives

- To investigate the relative impact of various hydro-meteorological and land use / land cover factors on lake level rise and lateral expansion of the lake
- To come up with defined lake level changes in time series.
- To predict future lake size changes
- To investigate the previous and existing environmental and socio-economic impacts associated with the expansion of the lake.
- To propose remedial measures.

1.4 Methodology

To achieve the objectives cited above, the following methods of investigations were applied in this study.

Review of the previous studies the analysis of previous studies (indicated above in section 1.1) to serve as supporting evidence in building up of meaningful generalization for what is currently taking place in and around the lake.

Acquisition of primary data/ information discussions and consultations were conducted with relevant organizations at the site such as, Ministry of Water Resources, Metehara Sugar Estate (MSE), Awash National Park (ANP), Metehara Town Council (MTC) and permanent dwellers in the catchment's area, and different time Land sat images have been used to build primary database. On top of this, Intensive fieldworks were carried out to achieve the aforementioned objectives.

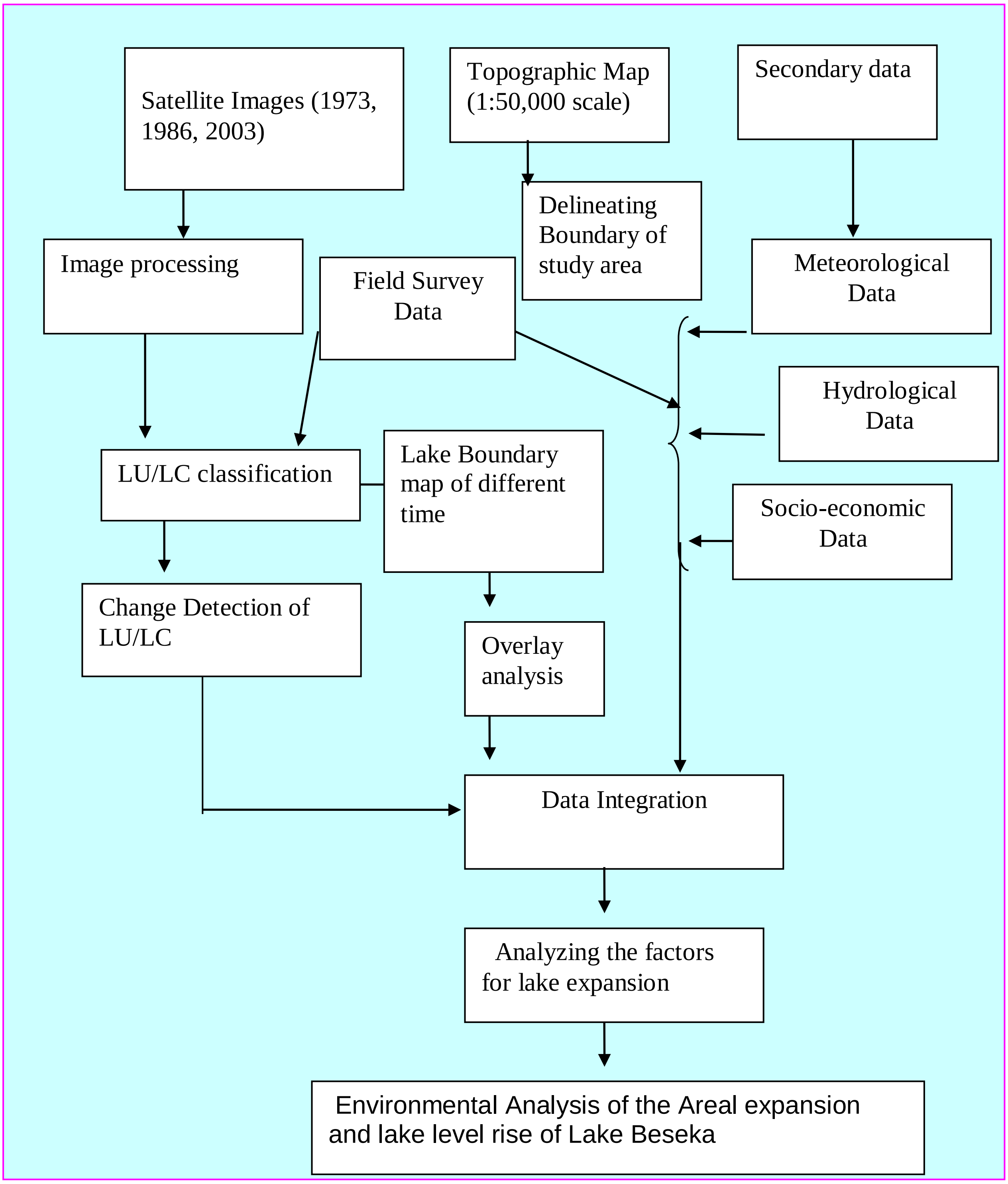

Fig. 1.1 Schematic view of the methodology followed

The following materials were used in the current investigation: satellite images (Land sat images of the year 1973, 1986, and 2003); RS-GIS soft wares: ERDAS, ENVI, ArcGIS, and GPS receiver for ground truthing.

CHAPTER TWO

2. THE STUDY AREA

2.1. Location and Accessibility

The study area is located in the East Shewa zone Fentale Wereda of the Oromia National Regional State, 195 km east of Addis Ababa, near Metehara town, on the Addis Ababa-Djibouti highway (Fig. 2.1). It is geographically bounded by 39°46'47"E and 39°55'40"E longitudes and 8°45'30"N and 9°00'00"N latitudes and occupies an area of about 424.5 km^{2}. Most of the site is easily accessible with vehicle.The elevation of the lake and its surrounding are between 900 and 1000 m a.s.l. The lake catchment has its longer dimension along the North-east to South-west direction, bounded in the North by mount Fentale and in the South-east by Dodoti ridge. It runs parallel to the River Awash, but is prevented from draining into it by an uplifted basaltic ridge. Slope of the catchment is steepest in the North and West (exceeding 80% on the slopes of Mount Fentale) and least on the exposed lacutrine sediments of the valley floor (less than 1% near Abadir Farm).

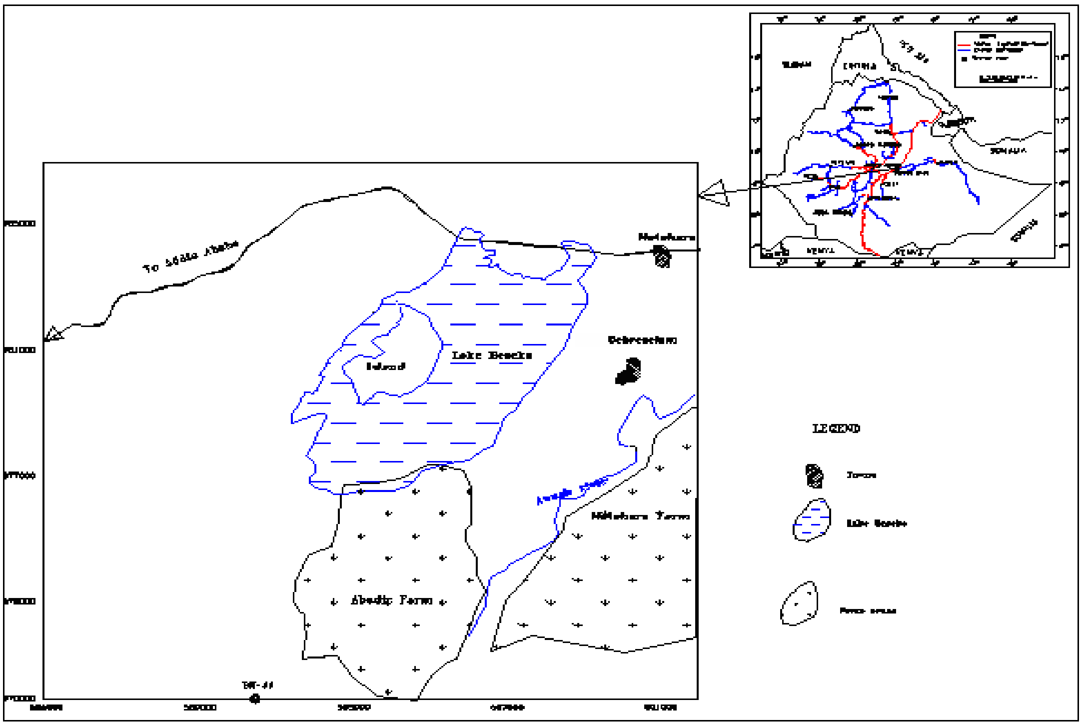

Fig 2.1 Location Map of Lake Beseka (Adopted from MoWR, 1999).

2.2 Geology

The geology of the area is given in Fig.2.2. Lake Beseka is part of the large lakes formed during Pleistocene, in the pluvial periods (MoWR, 1998). The products of Fentale, a Quaternary strato-volcano, mainly dominate the geology of Lake Beseka area. This volcano is predominantly composed of trachytes, rhyolites and pyroclastics of fissured origin associated with the Wonji Fault Belt.

Different stages of volcanic eruptions were observed in this area. The initial stage of the eruption resulted in the release of trachytic lava, which is exposed southeast of Fentale volcano. The activity continued with the effusion of rhyolites, obsidian and interrelated pyroclastics, mainly pumice. The final stage of the Fentale volcano was characterized by the eruption of a very extensive welded ash flow tuff, Fentale Ignimbrite, which caused the summit caldera to collapse.

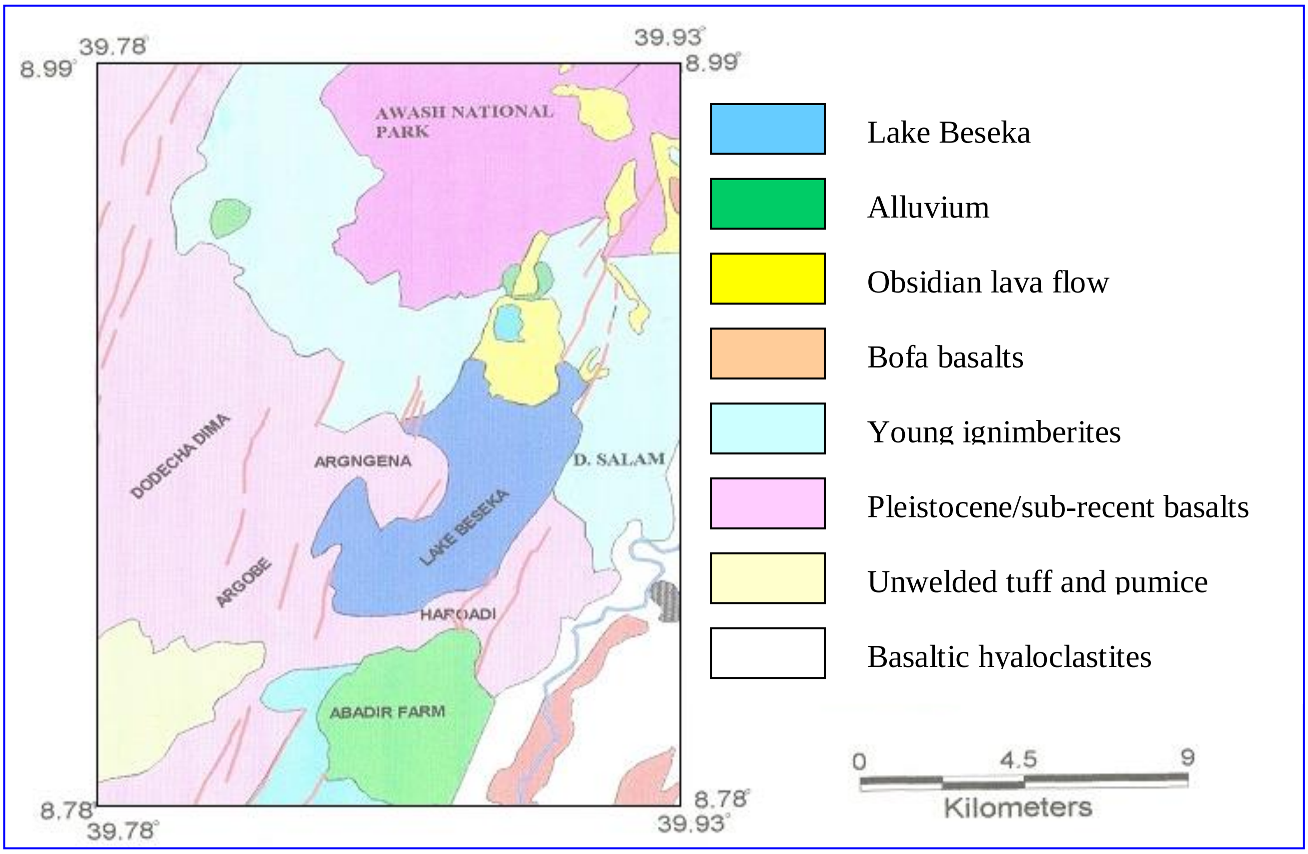

Fig 2.2 Geological map of Lake Beseka catchment (Adopted from EIGS, 1998).

The ignimbrites forming isolated blisters are believed to have formed by the presence of steam which could have been produced by the sudden vaporization of water from shallow lake or swampy areas beneath the flow at the moment of eruption. Some of the blisters are complete and others are ruptured by secondary steam explosion (Gibson, 1970 cited in MoWR, 1998).

In the northwest of the lake several hyaloclastites cones and tuff rings are identified. The hyaloclastites are results of a sudden contact of basaltic magma with cold water or saturated sediment. The northern portion of the lake is covered by basalt flow, which has erupted between 1810 and 1839 (MoWR, 1998) through 94 km long fissure system.

Pleistocene to sub-recent basalts underlay much of the surrounding area of the lake; often fairly coarse grained with phenocrysts .These rocks are exposed in most of the fault scarps near the perimeter of the lake. In addition to basalts, recent deposits (alluvial clays and silts) occupy Metehara and Abadir farms. Lacustrine deposits covered some parts of the lake surroundings.

2.3 Land use/ land cover

The area is physiographically characterized by the volcanic ridge of Mount Fentale in the North and the Awash River valley to the Southeast. The altitude of the area ranges from 750 m a. s. l. in the Awash River gorge to about 1900 m a. s. l. at the top of Mount Fentale in a semi-dormant Volcano with still smoking caldera. Other major topographic features of the Lake area are the Lava flow and the surrounding plains.

According to MoWR (1999, in the Beseka Lake catchment eight major landform units are identified. These units are flat to undulating plains, hummocky plains, hilly plain, volcanic cones, high Gradient Mountain, high gradient hills, medium gradient hills and elongated ridges.

The plains form flat to undulating topography (58.1%) with hummocky ridges of lava flows (3.5%) and they occupy the major parts of the catchment.

This landform includes flat, undulating and slightly sloping ridges, which ranges from 0-8% slopes and include the hummocky lava flows concentrated on the north part of the catchment near Lake Beseka. They are with dominant rock outcrops and stones. Almost all soil types in the catchment area occur in these landforms. These units have relief intensity of < 100m/km.

- The hilly plains occupy northwest of the catchment. These units include undulating plain plus 15-50% medium to high gradient hills with variable slopes, which cannot be mapped separately. The dominant soils in this unit are Lepthosols with common to much rock outcrops. Stones and few other soil units exist in this landform unit.
- The volcanic cones have similar slope gradient and relief intensity to that of medium gradient hills except their dome shaped nature and volcanic mouths on top. These features are concentrated in the west and very few towards south.
- The high gradient mountain occurs in the northern part of the Lake Beseka catchment including the Fentale Mountain. Part of this landform unit lies in the Awash National Park. The slope gradient is steep exceeding 30%; the dominant soils in this unit are Lepthosols with dominant rock outcrops and stones. It has relief intensity of greater than 600m/2km.
- High gradient hills are landforms having slope gradient >30% with relief intensity <600m/2km, and they occupy the northwestern and western parts of the catchment.
- Medium gradient hills are found in the southern parts of the catchment; these units have slope range of 8-30% with a relief intensity of grater than 25m/slope unit.
- The elongated ridges occupy the southern and central (near the lake) parts of the catchment, which covers small parts of the catchment than other units. It has slope < 30% and relief intensity greater than 25m/slope units. Lepthosols are the dominant soils in these units next to rook outcrops and stones.

Generally, Lepthosols are the dominant soils on plains, hilly plains, mountains, hills and elongated ridges with dominant rock outcrops and stones.

2.4 Climate

The climate in the area is characterized as semi-arid with mean annual temperature of about 25^{0}c, categorized as ‘kola’ (warm temperature). The mean minimum and mean maximum humidity is 25% in June and 86% in January, respectively. The measured evaporation data gives a mean annual pan evaporation of about 2560 mm (MoWR, 1999). The mean annual rainfall on the bases of 30 years of observation is about 540 mm. Records of sunshine hours vary from 7.4 hrs in July and August to above 9.4 hrs in November and December.

2.5 Hydrogeology of the lake catchment area

The lake catchment area as determined from 1:50,000 scale topographic maps is about 424.5 Km^2, including the surface of the lake (Fig.2.3).

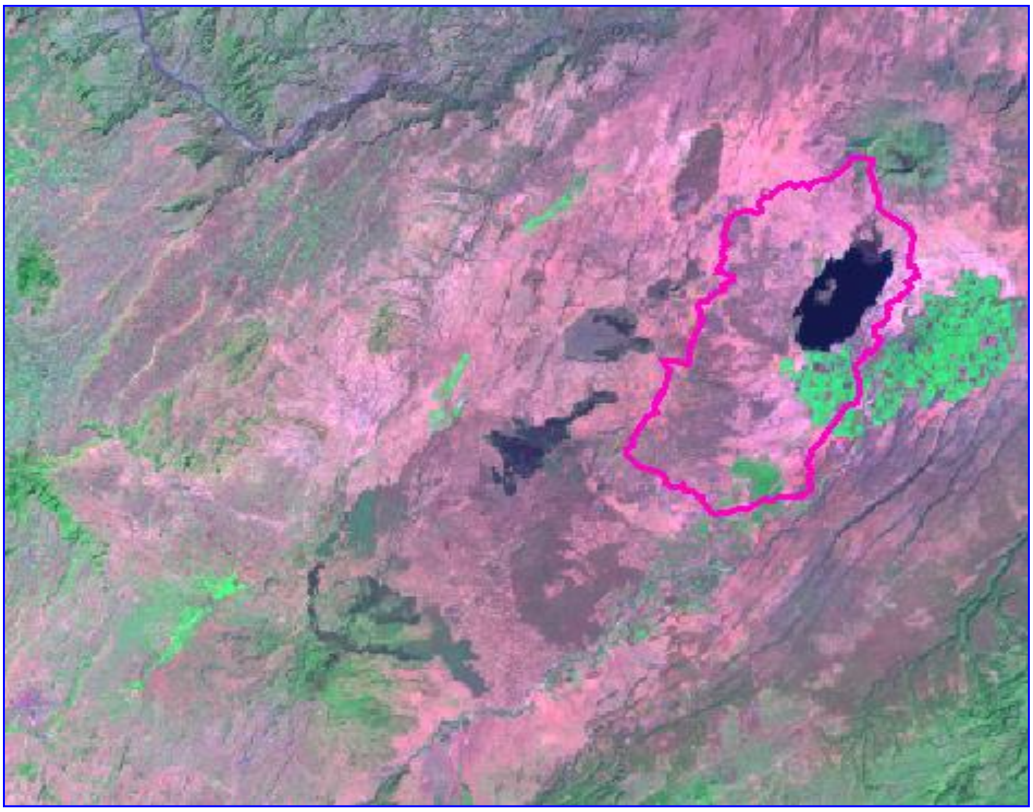

Fig 2.3 Catchment of Lake Beseka (adopted from Goerner, A., 2005)

The current size of the lake surface area is found to be about 43 Km^2. Hence, the effective catchment area at present is about 381.5 Km^2. The hydrogeological condition of the catchment is characterized as highly permeable composed of volcanic ash, sub-recent basalt and young basalt

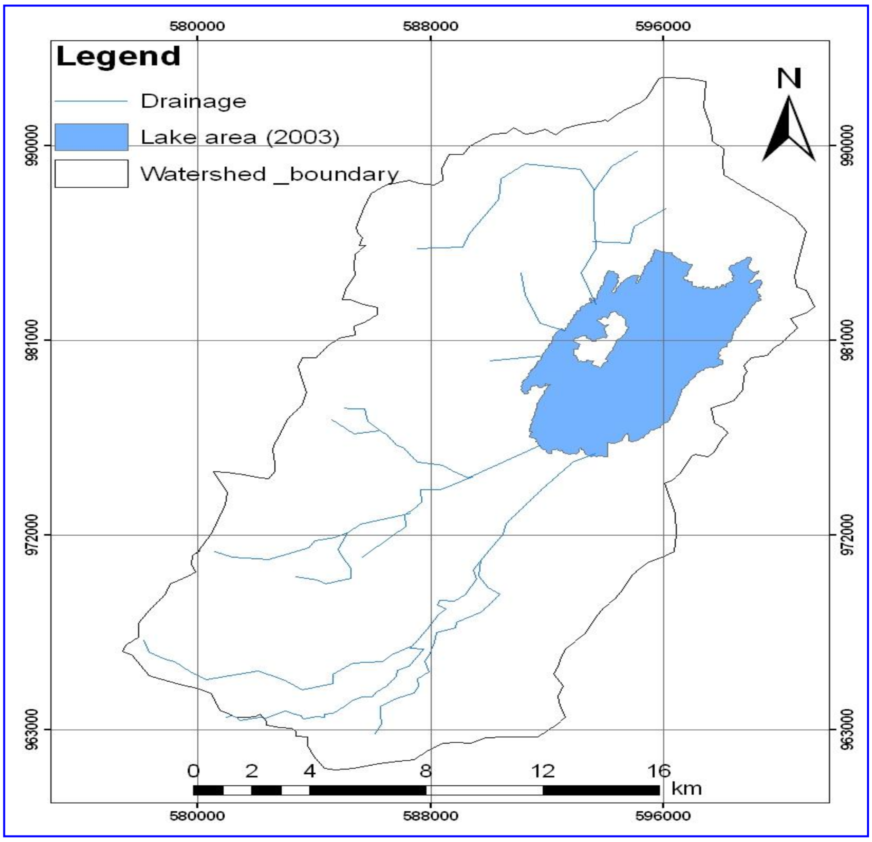

Fig 2.4.Drainage map of Lake Beseka catchment (adopted from Goerner, A., 2005)

There is no well-defined drainage pattern (Fig 2.4) except west of Abadir farm where dense stream networks originate in the mountains situated to Southwest of the lake area and along the foothills of mount Fentale, having steep parts with well-defined drainage pattern that disappears in short distance downstream. The streams are intermittent and seasonal, which disappear without reaching Lake Beseka. In general, this situation highly reduces the surface runoff that flows into Lake Beseka

2.6 Water Resources of the Lake Beseka Area

The water resources in the project area include hot springs, cold springs, groundwater, Awash River and Lake Beseka.

2.6.1 Hot springs

There are numbers of hot springs in the lake Beseka catchments, but the most important ones are Tonne and Chelelektu springs. They are situated at the southern end of the lake. Their surface temperature is about 43^{o}c and they discharge significant volume of water to the lake. There are also some submerged hot springs inside the lake and hot water seepage through out the southwest periphery of the lake (MoWR, 1999).The water of these hot springs has high concentration of EC, pH, Na^+ and HCO_3^-. Like Lake Beseka water, the divalent cat ions such as Ca^{++} and Mg^{++} are very low. Water from these springs is not suitable for human consumption and irrigation purposes (MoWR, 1999).

2.6.2 Cold spring

There is a cold spring situated at the northern end of the lake Beseka near to the Rail line. It is locally known as Abdula-tebel.

The water quality of this spring is different from that of the other water sources in this area. It has very high concentration of Nitrate, Sulfate and Calcium (MoWR, 1999). It is very hard water as compared to hot springs and Lake Beseka water.

The major ionic composition is Calcium Sulfate. It contains relatively low concentration of Fluoride and Bicarbonate ions. Contrarily to the alkaline nature of the hot springs and Lake Water, this spring is neutral and its pH is about 7. The discharge rate of this spring seems insignificant as compared to the hot springs in the lake catchment.

2.6.3 Ground water

Ground water in the lake area is generally unconfined. The temperature of the ground water around the Lake varies from 36 to 42^{o}c except in the Merti Sugarcane Farm area (MoWR, 1999).

Groundwater quality in the lake Beseka area is generally unfit for drinking purposes. Especially those ground waters situated near to the lake in the eastern direction contain very high concentration of fluoride and other salts. Excess fluoride in drinking water is toxic and it causes bone and teeth fluorosis.

2.6.4 Awash River

The Awash River rises on the high plateau to the west of Addis Ababa, at an altitude of about 3000m a.s.l. It then flow east wards and finally terminates in the lake Abe at an altitude of about 250 m a.s.l. The total length of the main river course is some 1200 km. The mean annual flow at Awash station amounts to some 1097 Mm^3. About 55% of this run off occurs in the period July to October (MoWR, 1999).

The Awash River, meandering in a southwest to northeast of the lake Beseka. It is the only big river passing near by the lake. The shortest distance between the lake and the river is about 3 km (MoWR).

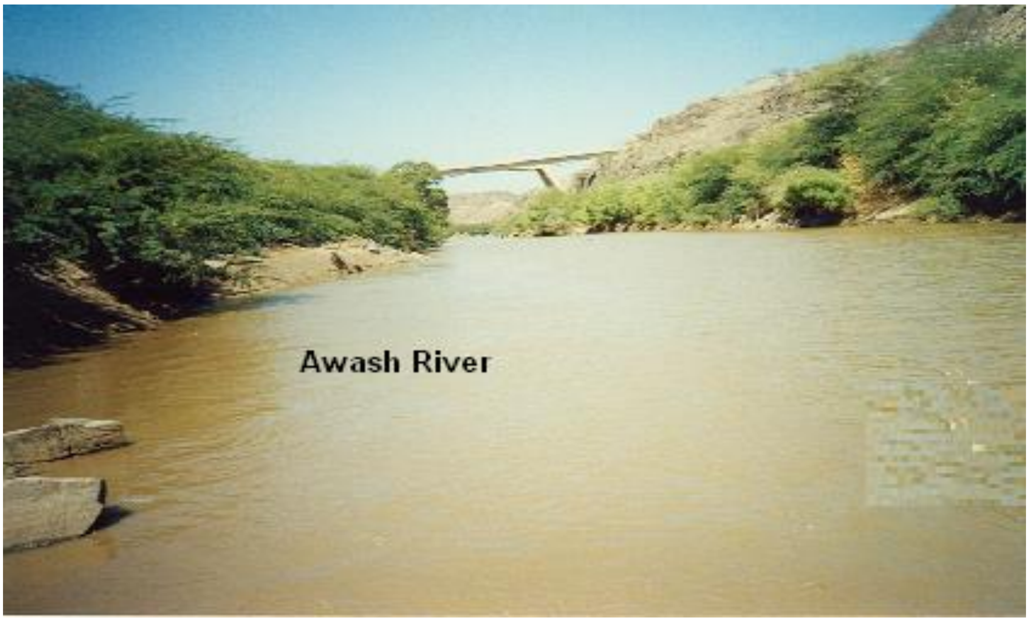

Fig.2.5 Awash River (Amare, B., 2005)

High turbidity, low EC, low Cl, relatively low fluoride, high sodium and high bicarbonate concentrations characterize the water quality of Awash River. The water quality of Awash River is suitable for irrigation and it has been used for irrigation more than any other Rivers in the country. However, due to the high turbidity and high bacterial pollution, it is not fit for drinking and domestic uses without water treatment.

CHAPTER THREE

3. LAKE WATER BALANCE MODELING

3.1 Hydro-meteorological Data Analysis

The data used in this study consist of meteorological and hydrological data from the archives of the National Meteorological Services Agency (NMSA) & Hydrology Department of Ministry of Water Resources (MoWR). The data had been recorded within the Beseka lake catchment

The major meteorological elements that are directly related with lake level rise and areal expansion of the Lake are rainfall, evaporation, relative humidity, wind speed, sunshine hours, and temperature. However, in most cases the meteorological elements remain close to the long-term mean values with no significant departure. Low variations have been observed in annual series.

The available meteorological data have been plotted in modular values. The analysis of these meteorological data has paramount importance for understanding and predicting the lake level rise and areal expansion of the Lake.

3.1.1 Precipitation

The available mean monthly precipitation records cover the period 1976 - 2005 and are provided in Annex I. The mean annual rainfall based on 30 years of observation is about 540 mm by averaging condition of Meteorological station located at the town of Metehara (NMSA) and shown in Fig. 3.1.

Considering the 30 years precipitation data, the mean monthly rainfall distribution pattern of the area could be noted that, the area has received maximum rainfall in August and July, which are 126.1 mm and118.3 mm respectively. In addition minimum rainfall in November and December which are 9.9 mm and 8.6 mm respectively.

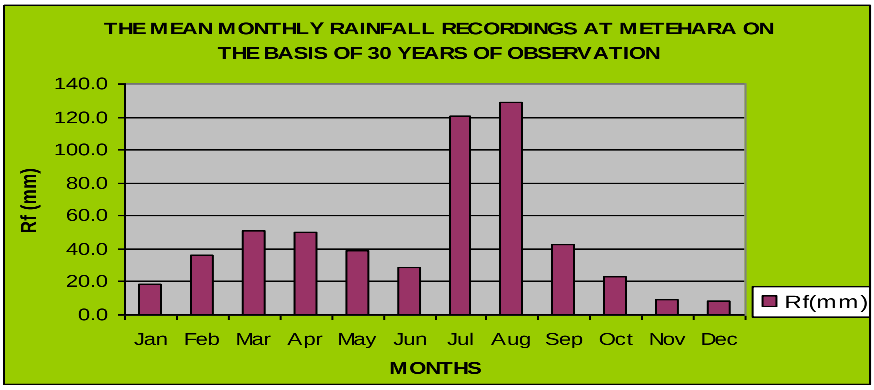

Fig. 3.1 Mean Monthly rainfall of the area (data from 30 years average at Metehara station).

3.1.2 Evaporation

Evaporation is one of the factors that control the hydrological condition of lakes. The rate and amount of evaporation is affected by the temperature, wind speed, sunshine hour, and relative humidity of the area.

The available measured pan evaporation from class 'A' pan (most probably U.S) for the period 1976 - 2005 has been used for computing lake water evaporation (provided in Annex II. The mean annual pan evaporation is about 2560 mm. The data has been collected from Metehara Meteorological Station (NMSA) and Hydrology Department of Ministry of Water Resources and is shown in figures 3.2 and 3.3. The values of pan evaporation are slightly lower for semi-arid areas such as Metehara. High rate of evaporation is recorded during the months of May and June which could be because of high temperature during those months prevailing in the area.

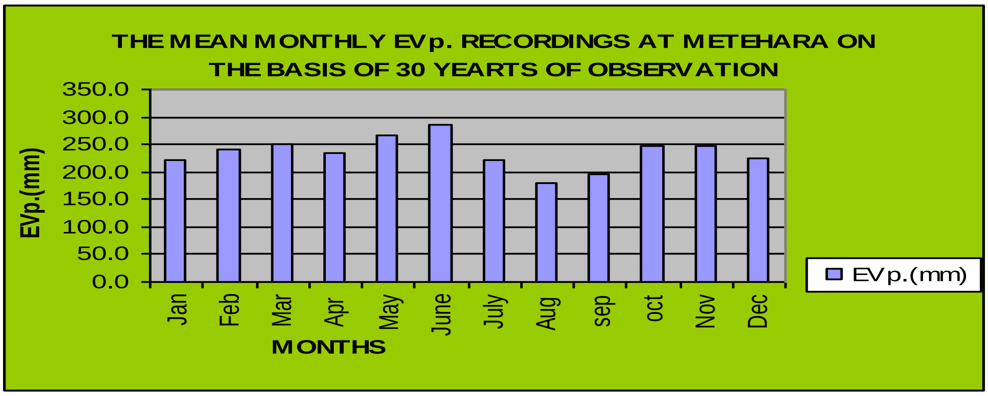

Figure 3.2. Mean monthly evaporation of the area (data from 30 years average at Metehara station).

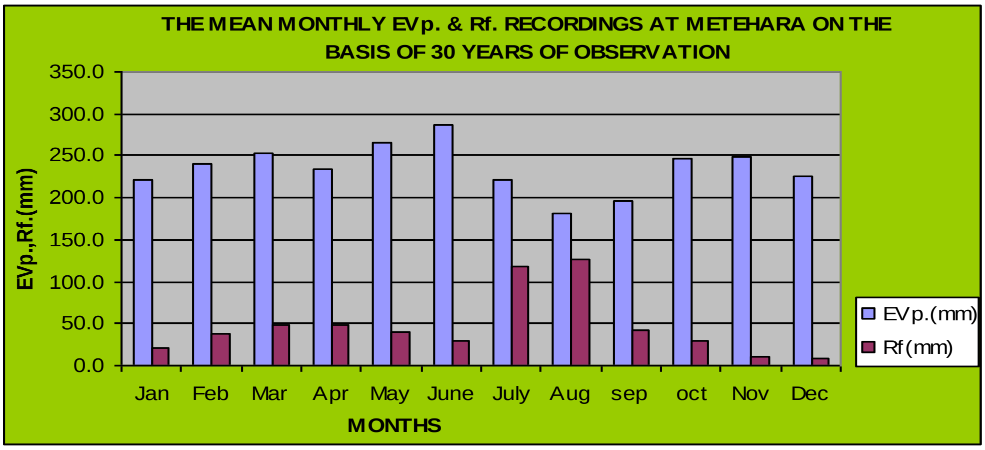

Fig. 3.3 Mean monthly evaporation and rainfall data of the area (data from 30 years average at Metehara station).

3.1.3. Temperature

The minimum and maximum temperatures recorded at Metehara station depict that monthly variation in temperature is low, which characterizes the semi-arid nature of the climate prevailing in the area. The mean monthly temperature varies from about 13.7 °C in December to 36.5 °C in June .The available data are provided in Annex III and shown in figure 3.4.

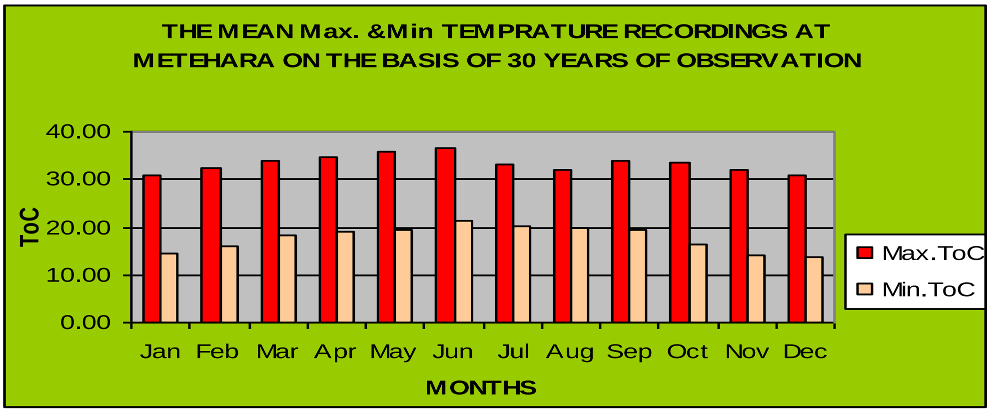

Figure 3.4 Minimum and Maximum temperature of the area (data from 30 years average at Metehara station).

3.1.4 Relative humidity

The available recorded data of relative humidity covers the period 1976-2005 with mean minimum and mean maximum relative humidity of 29.81% in June and 81.5% in April, respectively. The available data is provided in Annex IV and shown in figure 3.5.

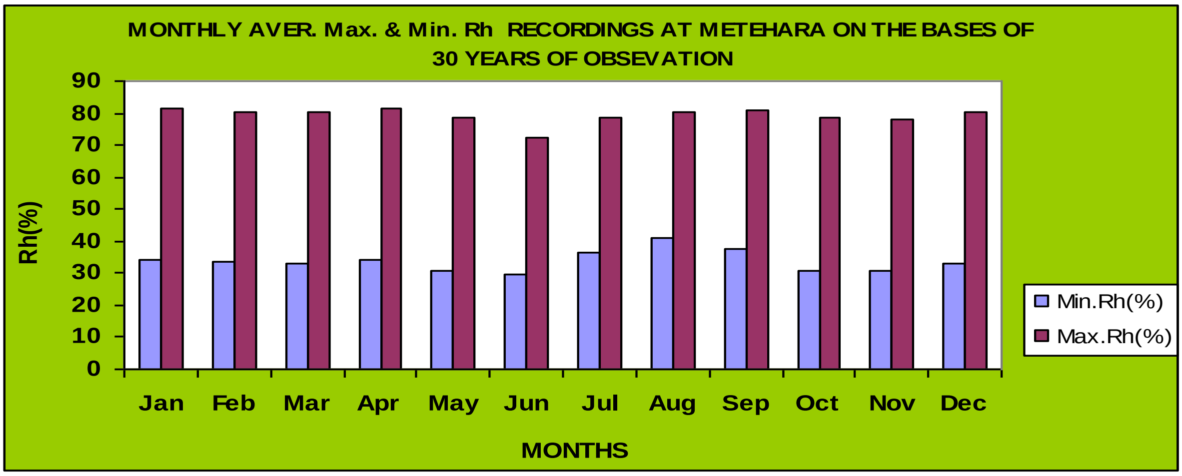

Figure 3.5 Relative humidity of the area (data from 30 years average at Metehara station).

3.1.5 Sunshine hours

The sunshine hours vary from 7.4 hrs in July and August to above 9.5 hrs in November and December. The available data is given in Annex V, and depicted in figure 3.6.

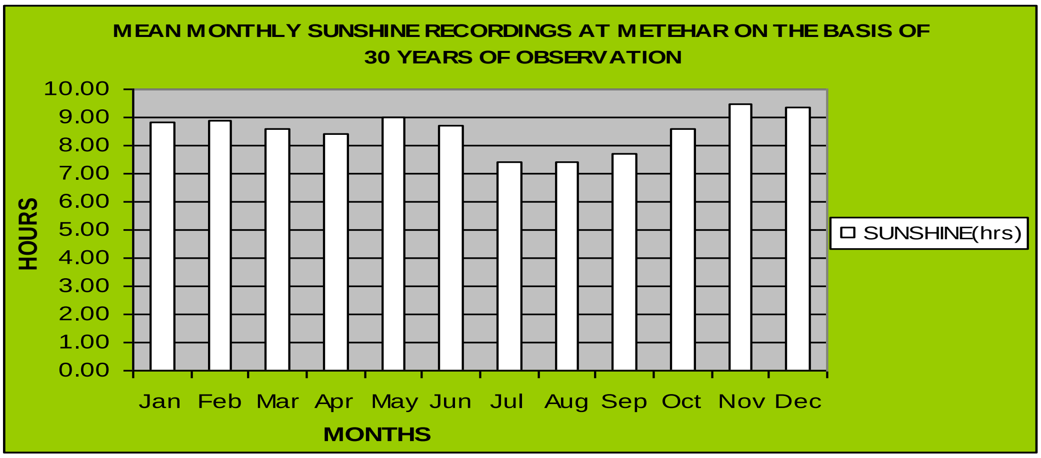

Fig 3.6 Mean monthly sunshine records (data from 30 years average at Metehara station).

3.1.6 Wind Speed

The available recorded wind speed data collected from Met station (NMSA) (located in the proximity of the study area) is provided in Annex VI and shown in figure 3.7.

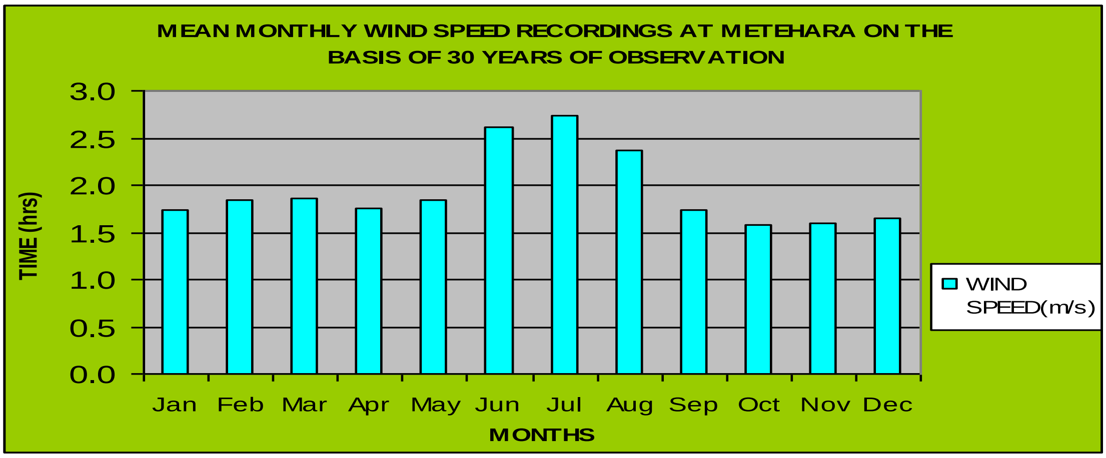

Figure 3.7 Mean monthly wind speed of the area (data from 30 years average at Metehara station).

3.2 Lake Level Records

Lake level records for the period July 1976 – March 2005 has been made available after infilling of the gaps by means of trend line fitting of the gauged levels in time series order and taking into account R^2 (the regression (R^2) is developed for the estimation dataset) as a measure of good prediction of the regression model. Mean Monthly water level records are provided in Annex VII.

For computing change in storage of the lake reservoir, change in level has been determined in consecutive months from the year of commencement of lake level record in 1964.

Period	Change in level (m).	Source.
1964 - 1972	1.95	MoWR Dept. of Hydrology
1972 - 1978	4.19	MoWR Dept. of Hydrology
1978 - 1998	3.74	MoWR Dept. of Hydrology
1998- 2005	1.83	MoWR Dept. of Hydrology

For the last 42 years, the lake has most probably experienced change in level of about 11.7 m. The highest change in level was observed during the period 1972 – 1978 which is about 4.19m.

The period 1977- 2005 has been considered for computation of the lake water balance as a complete data set is available only for this period, although lake level recording started more than a decade earlier.

3.3 Water Balance Components

The basic storage equation, which has been applied for a closed lake like Beseka would assume the following form in computing the water balance over a specified period.

$$I - O = \pm \Delta S$$

Where
- I= the total inflow components
- O= the total outflow components
- ΔS= change in lake storage

3.3.1 Inflow components

1. Rainfall on Lake Surface

The available rainfall record, for the period 1976 - 2005 has been considered for computing the inflow magnitude to the lake. The rainfall station located at Metehara has been selected by virtue of its class and long period of observation and consistency of the database with adjacent stations. Since the water balance is conducted based on yearly time interval, annual rainfall series have been adopted.

Inflow due to rainfall on the lake surface is computed from the equation

$$R = \frac{PPt * ARF * A}{1000}$$

Where
- R= Inflow in mcm
- PPt= Precipitation in mm
- ARF= Area reduction factor
- A= Mean surface area of the lake for each year in km^2

2. Runoff from the catchment of the lake (excluding the lake surface-known as effective catchment)

As observed during the rainy season, high runoff enters to Lake Beseka in almost all directions by natural and artificial drainage ways. Runoff from mountains, hills and plains enter into the lake In the northern part. In the southern part, especially in between Lake Beseka and Abadir farm, the constructed dike to protect the farm from flooding, collects all the runoff from the western and northwestern areas and drains into Lake Beseka as a big stream flow. The total runoff to the lake from the effective catchment is given by the equation.

$$CR = \frac{ARF * K * PPt * AEC}{1000}$$

Where
K= Runoff coefficient
CR= Catchment runoff in Mcm
PPt= Precipitation in mm
ARF= Area reduction factor
AEC= Effective catchment area in km^2

The runoff coefficient is estimated to be in the order of 10%, taking into account the spatial variation of the catchment and the fact that the geological materials underlying the catchment are highly permeable and to some extent the rainfall characteristics of the area.

3. Groundwater and spring inflow (GR)

As it is difficult to quantify the contribution of each spring in the area, the spring inflow is lumped together as groundwater inflow (GR) and obtained in the water balance computation by balancing with change in storage.

According to MoWR (1999), the concentrated flow from Abadir Farm area, Tone springs, submerged springs, and other sources are summarized as follows:

- Groundwater flow from the western side of Lake Beseka is about 133,552 m^3/day (simulated) and 133,500 m^3/day (analytic);
- Spring discharge 129,062 m^3/day (simulated), and 129,720 m^3/day (analytic);
- Groundwater from under the Lake 4,460 m^3/day (simulated) and 3,780 m^3/day (analytic).

3.3.2. Outflow Components

1. Evaporation

The available measured pan evaporation has been used in estimating open water evaporation by applying pan coefficient of the order of 0.8.

Evaporation has been computed by using the following equation

$$E = \frac{A.\ Ep.C.}{1000}$$

Where E= Evaporation loss in mcm
A= Mean surface area of lake in km^2
Ep= Pan evaporation in mm
C= Pan Coefficient

2. Lake Water intrusion to the groundwater

This could probably be expected in small magnitude with its seasonal variation. However, it is required to be quantified, currently assumed to be negligible. Quantification could be realized through subsurface investigation and subsequent monitoring for a certain period.

3.3.3 Water Balance Computation

For a period of 29 years starting 1977 until 2005 change in lake storage (ΔS) is calculated using the following equation:

$$\pm\ \Delta S = \Delta h\ (A_1 + A_2)/2$$

Where A1= Surface area of lake at beginning of year
A2= Surface area of lake at end of year
Δh= Change in lake level

The water balance modeling is conducted by equating the inflow and outflow components to the change in storage caused by the change of lake level. This has been realized by means of balancing the two sides of the following equation:

$$R + CR + AR + GR - E = \Delta h\ (A_1 + A_2)/2$$

For each year, balancing has been done and results of the water balance modeling are provided in table 3.1 and shown in figure-3.8

Table 3.1 Water balance Computation

Year	(A1+A2)/2	Change in level(m)	Lake surface PPt (mm)	R (mcm)	Out flow E (mcm)	in flow CR (mcm)	Abadir farm (mcm)	∆S (mcm)	Balance (mcm)	GR (mcm)
1977	30762307	0.571	826	22.87	75.34	28.29	20	17.57	-4.18	21.74
1978	31692567	0.078	442	12.61	74.13	15.1	20	2.47	-26.42	28.89
1979	31569297	-0.164	513	14.58	68.69	17.54	2.52	-5.18	-34.06	28.89
1980	31190886	-0.1	465	13.05	83.75	15.91	2.3	-3.12	-52.48	49.36
1981	31413059	0.255	643	18.18	73.1	21.99	3.24	8.01	-29.69	37.7
1982	32312388	0.396	863	25.1	73.96	29.44	0.08	12.8	-16.34	29.14
1983	32929516	0.071	590	17.49	79.89	20.1	3.36	2.34	-38.94	41.28
1984	32883754	-0.11	323	9.56	90.59	11	3.32	-3.62	-66.71	63.09
1985	33024561	0.23	550	16.35	70.57	18.73	2.12	7.6	-33.38	40.97
1986	33188835	-0.09	436	13.02	62.3	14.84	2.39	-2.99	-32.04	29.05
1987	33153633	0.06	377	11.25	56.3	12.83	2.24	1.99	-29.71	31.69
1988	33400045	0.15	539	16.2	72.01	18.34	1.06	5.01	-36.41	41.42
1989	33728593	0.13	547	16.6	57.17	18.6	0.84	4.38	-21.13	25.51
1990	34162747	0.24	739	22.72	62.52	25.09	1.83	8.2	-12.87	21.07
1991	34667399	0.19	573	17.88	71.48	19.43	2.19	6.59	-31.98	38.57
1992	35131534	0.19	557	17.61	72.83	18.87	2.27	6.67	-34.08	40.75
1993	35562968	0.15	652	20.87	68.46	22.06	1.76	5.33	-23.77	29.1
1994	36007092	0.2	558	18.08	70.36	18.89	2.49	7.2	-30.93	38.13
1995	36438526	0.14	414	13.58	75.65	13.98	2.6	5.1	-45.49	35.59
1996	37149934	0.39	631	21.1	77.49	21.26	2.89	14.49	-32.24	46.73
1997	38246808	0.31	522	17.97	71.22	17.54	2.77	11.86	-32.94	44.79
1998	39391203	0.32	540	19.14	84.18	18.09	3.38	12.61	-43.56	56.17
1999	39391203	0.2	532	22.44	80.67	21.21	2.43	2.98	-33.56	45.6
2000	40043327	-0.54	502	22.81	82.01	21.17	2.43	2.61	-33.41	35.5
2001	41258250	-0.55	427	23.5	84.5	21.1	2.43	3.39	-30.52	37.5
2002	42202200	-0.58	322	24.04	86.43	21.05	2.43	8.45	-29.33	35.5
2003	42964500	-0.6	461	24.48	87.99	21.01	2.43	6.57	-27.33	32.5
2004	43726800	-0.62	578	17.04	89.55	14.34	2.43	-3.24	-34.13	38.5
2005	44489100	-0.76	579	17.63	91.11	14.31	2.43	-4.53	-33.89	32.5
	Mean	**0.01**	**541.39**	**18.2**	**75.66**	**19.04**	**3.54**	**2.96**	**-32.12**	**36.15**

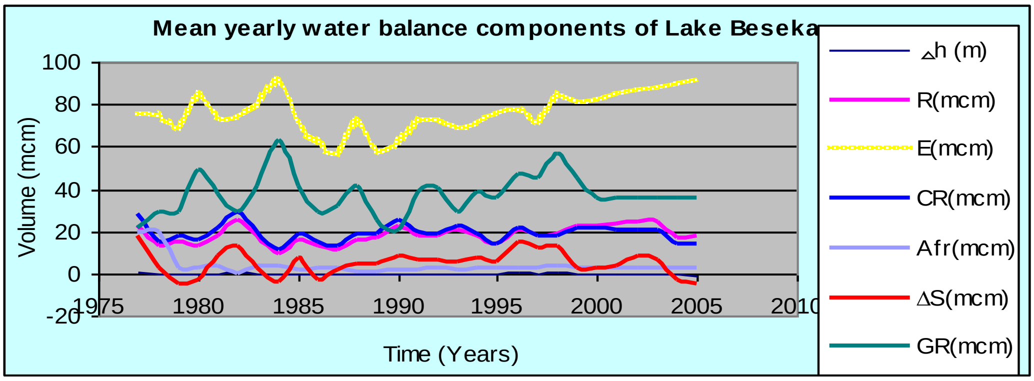

Figure 3.8 Water balance components of Lake Beseka.

3.3.4 Discussion on the water balance components

The modeling shows that the rate of open water evaporation generally increases with decrease in storage change. Rainfall on Lake Surface and runoff from effective catchment follow the same trend as that of storage change. Low rainfall periods relatively manifest high lake water evaporation and high rainfall periods relatively experience low lake water evaporation. Generally, high temperature, low relative humidity and strong winds result in higher evaporation loss and reduced storage change is observed. The wind action effect varies with relative humidity. In perfectly dry air, the maximum effect of wind action is considered to be doubled that of evaporation rate with still air. Since the magnitude of open water, evaporation is high, due to the semi-arid climatic condition of the area. The location of the pan should have been in ideal condition and very close to the open water surface of the lake. The average changes in storage for the last 29 years are found to be about 2.96 Mcm/year.

In the water balance modeling, the 1977 had been identified with the highest change in storage (17.57 Mcm). This was because of the fact that the surface irrigation application technique used in the drainage area was wild flooding with very long and open-end furrows. The last two years (2004-2005) exhibited a declining trend and relatively higher change in storage as compared to previous years. This happened because of the fact that MoWR has begun a controlled discharge of Lake Water into Awash River.

CHAPTER FOUR

4. LAND USE / LAND COVER MAPPING AND CHANGE DETECTION ANALYSIS

4.1 Land use/ Land cover mapping

Land use/land cover (LU/LC) changes can play a significant role in causing or triggering lake level changes. Land Use/land cover maps for the years 1973, 1986 and 2003 of the Beseka catchment have been developed from satellite images following standard principles and procedures of image classifications (Lillesand, M. et al.1999). The major land use/land cover units in the Beseka catchment are the water body, shrub land, active volcanic area, grassland, cultivated (irrigated and seasonal) land, and degraded lands (Fig. 4.1-4.3).

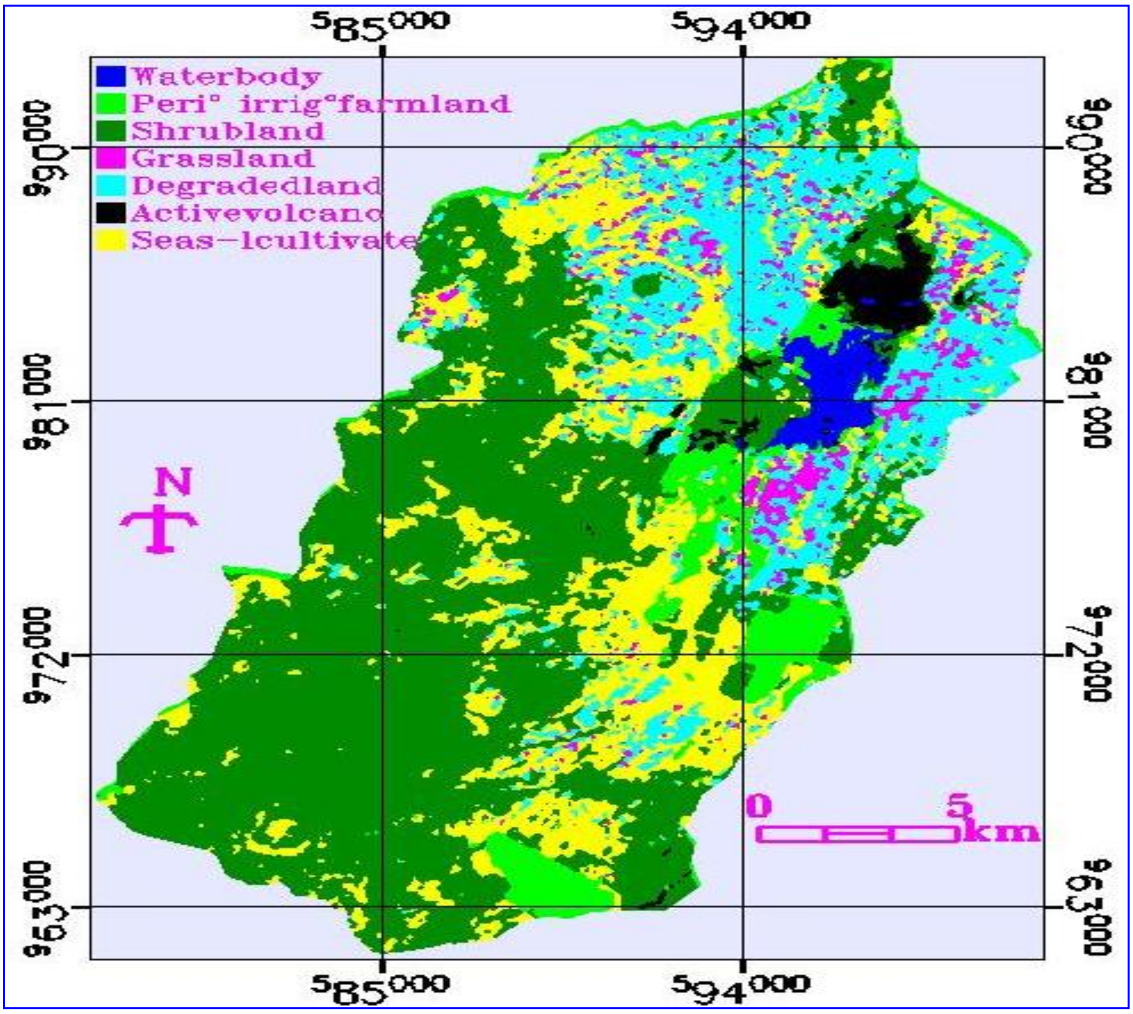

Figure 4.1 LU/LC map for the year 1973 of the Beseka catchment.

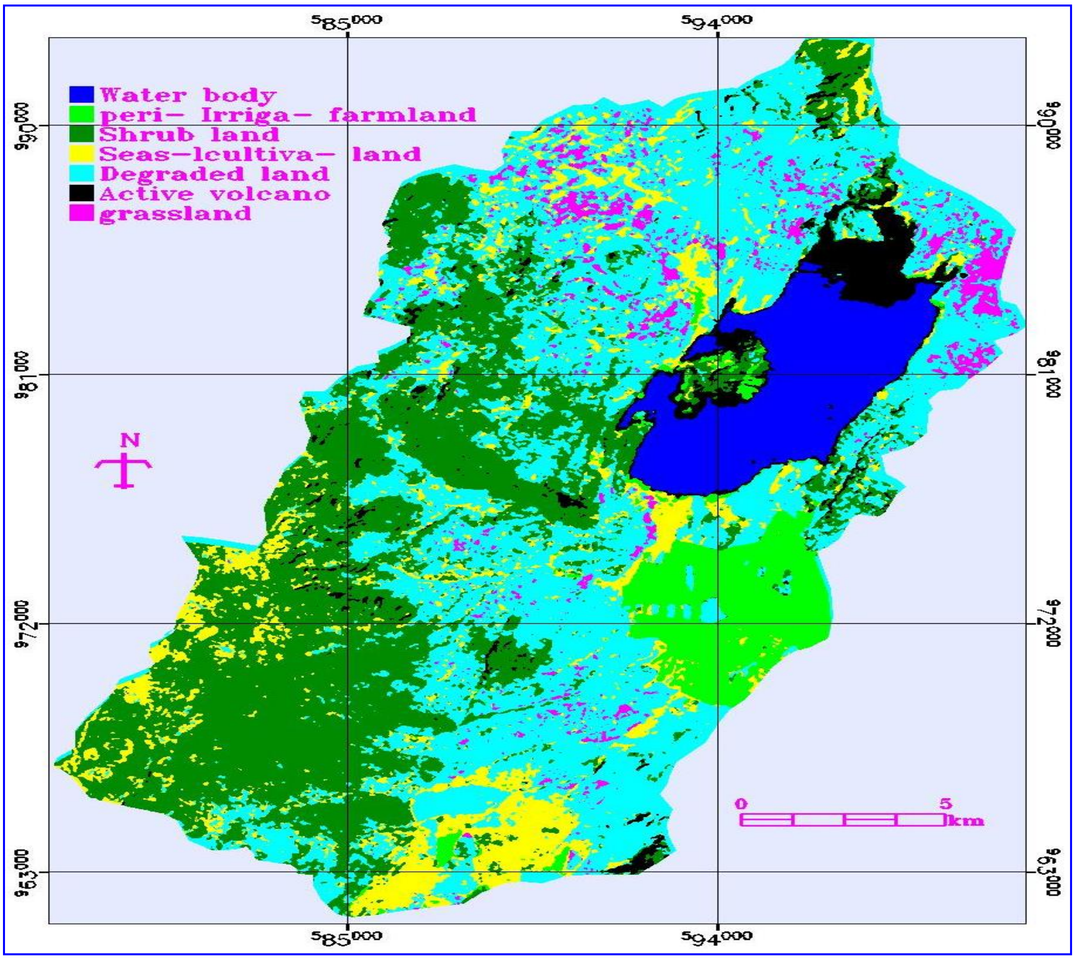

Figure 4.2 LU/LC map for the year 1986 of the Beseka catchment.

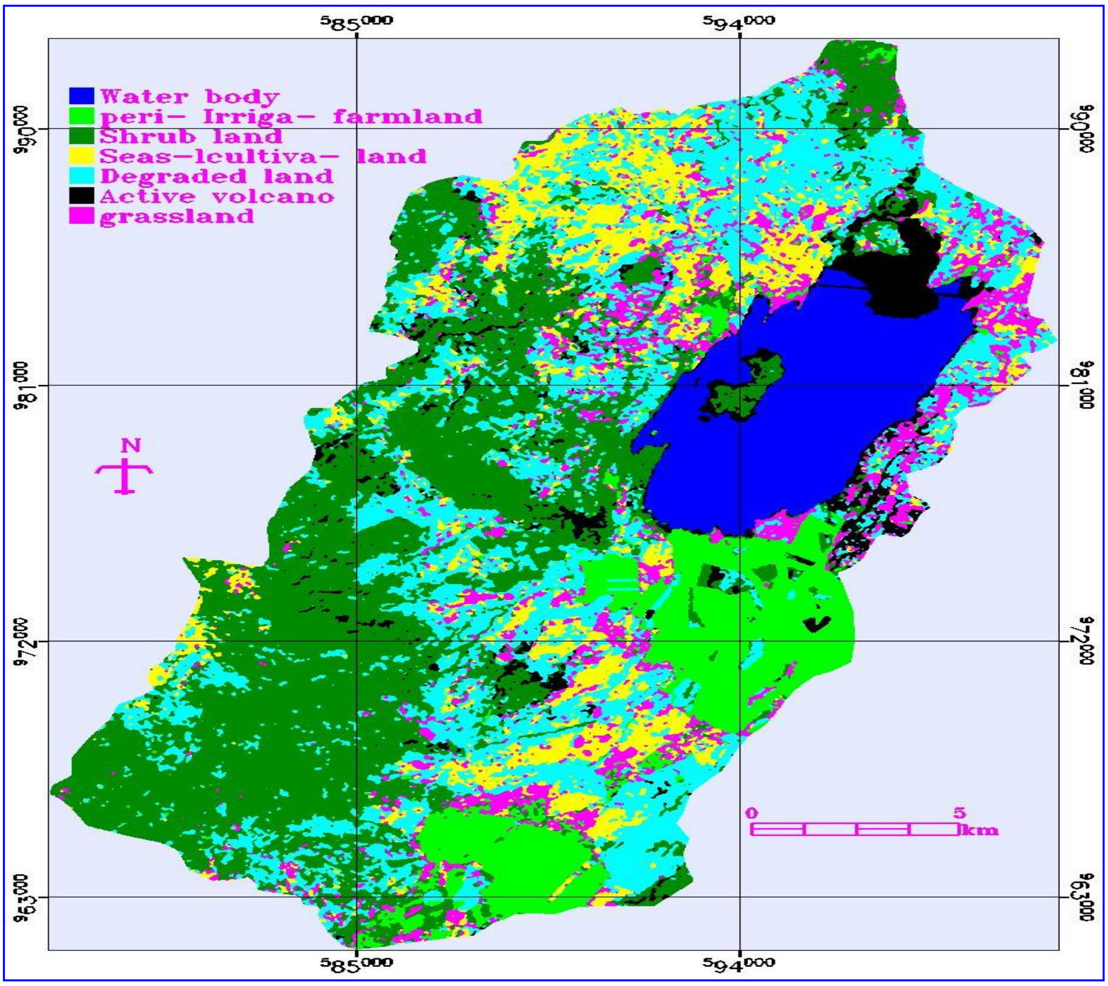

Figure 4.3 LU/LC map for the year 2003 of the Beseka catchment

4.1 Land use/Land cover classification

Land cover includes various features covering the earth's surface, such as water body, forest, and other vegetation, bare rock or sand, man made structures etc. These features can be directly observed on aerial photographs and often on satellite imagery.

Land use refers to the use that is made of the various land covers; e.g. grazing, timber production, agriculture, recreation (Game Park), fishing and the like. Different land cover types may be used for one land use and one type of land cover can have different land uses. Land use is often difficult to be observed directly from aerial photographs and even more difficult on satellite imagery.

It is generally inferred from a combination of image interpretation with detailed ground truthing (e.g. confirmation by local people, expert judgment at the time of field observation and additional secondary data from relevant sources).

All available information (field descriptions, aerial photographs, existing maps and satellite imagery) have been used for the land use/land cover classification and description. Based on all these data sources the following land use/land cover units were identified in the Beseka catchment (to the years 1973, 1986 and 2003)

- **Water body (Lake):** This unit refers to the water body of Lake Beseka that covers 10.13 % (2003) of the catchment and expanding through time. The main land use activity is fishing. Based on image classification, the water body has been classified with an over all accuracy of 84.44, 99.44 and 99.74 percent for the year 1973, 1986 and 2003, respectively.
- **Degraded land:** This unit is dominantly found to the north of Beseka Lake up to the foot slope of Mount Fentale and a small patch to the east of the Lake. These units are of volcanic origin (rocky rugged topography. This unit serves as a quarry for construction materials lava flow) without any vegetation, covered by either rock outcrop or bare soil or (as road aggregates)**.** This land use/ land cover class has been classified with an accuracy of 93.25, 95 and 98.48 for the years 1973, 1986 and 2003 respectively.
- **Shrub land:** This land cover unit includes the small trees and bushes, which have an opened canopy. This unit is found south-southeast of the catchment covering the elongated ridge and the medium gradient hills. Small portion of the eastern catchment also falls under this unit. The main land use activities are grazing, browsing, collection of firewood, and charcoal production. Based on image classification, this unit has been classified with an accuracy of 94.41, 96.64 and 97.58 percent for the years 1973, 1986 and 2003, respectively.

- **Active volcanic area:** This unit represents the area covered by the aa-lava basalts on the north and northeast shores of the lake that resulted from historical eruptions. They have been classified with greater accuracy since they can be easily identified from images. The accuracy of classification is 97.43, 98.21 and 98.62 percent for the years 1973, 1986 and 2003, respectively. The unit is barren.

- **Grass land:** This land cover includes areas dominantly covered with grass dotted with sparse vegetation and shrubs. Grasslands are found on the eastern side of the lake and extend towards northeast covering the plain up to the foot slope of Fentale Mountain, and in the Northwestern part of the catchment. These units are used for grazing and browsing. The accuracy of classification of this unit is 57.73, 73.43, and 81.64 percent for the years 1973, 1986 and 2003, respectively.

- **Irrigated (perennial) farmlands:** This land cover includes areas which are continuously cultivated using irrigation schemes. They are continuously covered by crops and appear ever-green. This land use is very common following wetlands like around the periphery of the lakes and rivers. This land use has been classified with an accuracy of 97.11, 93.66 and 94.21 percent for the years 1973, 1986 and 2003 respectively.

- **Seasonal crop (cultivated) lands:** Cultivation is hardly exercised in the Beseka catchment except in the Metehara Sugar Estate and Nura Era citrus farm. There are few scattered patches of cultivated lands being exercised by semi-nomads in various parts of the catchment. The land use is rain-fed agriculture of sorghum and maize. This unit is classified with an accuracy of 90.43, 92.14 and 94.73 percent for the years 1973, 1986 and 2003, respectively.

In general, the accuracy assessment for LU/LC mapping was 85.9 %, 65.8% and 91.2 % for the years 1973, 1986 and 2003, respectively.

4.2 Change Detection Analysis

A land use/land cover map can be generated from an image showing different land uses and land covers by the time the image was captured. Generating such maps in time series may reveal the dynamics of the ecosystem and the spatial relationship among elements during the period of analysis.

The land use/ land cover status for the Beseka catchment were identified through the classification of landsat imagery acquired in January 1973, 1986 and 2003 using ENVI 4.1 software. Land sat images acquired on Jan. 22, 1973 and Jan.11, 1986 were selected as the historical images and used for change detection against the Jan. 11, 1986 and 2003 images, respectively.

In this study, two phases of change detection were done (one is from 1973 to 1986 and the other from 1986 to 2003). The changes of land use/land cover categories were assessed and change detection maps for each land use category were prepared. The generalized spatial distribution and change statistics of land use/land cover changes in the study area are shown in figures 4.1 to 4.4.

4.2.1. Change detection from 1973-1986

Phase I. 1973-1986 Percent based LU/LC change

The image analysis of the change detection shows that the different land uses have been changed in different ways. During this period, the lake water body has increased by 301.3 % from 1973 to 1986. This is estimated to be an increase of 21.82 Km^2 area.

The increment of the lake area is due to the inundation of the different land uses surrounding it. The major land uses that were inundated due to the lake expansion are the grassland area where about 22.433% (i.e., about 3.4 km^2 area) of its area from 1973 was covered by lake water in 1986. The active volcanic area was also inundated where about 17.126 % (i.e., about 1.36 km^2 area) of its area from 1973 was covered by the lake in 1986 (Tables 4.1 and 4.2). In addition, the perennial irrigated land (25%) and the degraded land (17%) also are covered.

Phase II. 1973-1986 LU/LC change in area base (km^2)

Generally the lake expansion inundated the following areas from 1973-1986 (Table 4.2): 6.92 km^2 of Irrigated areas, 2.91 km^2 of Shrub lands, 3.41 km^2 grass lands, 4.81 km^2 degraded areas, 1.36 km^2 of the active volcanic areas and 2.57 km^2 seasonal crop lands.

Along with the lake expansion, the degraded and active volcanic lands are increased. which increases by 92.17 km^2 and 8.69 km^2, respectively. The degraded land increment resulted on the expense of the Shrub lands and seasonal croplands deceasing by 75.03 and 42.99 km^2, respectively.

		1973								
		Water body	Per_irrg_ farm	Shrub land	Grass land	Active volcanic area	Degraded land	Seasonal cultivated land	Row Total	Class Total
Unclassified		0.000	0.418	0.148	0.000	0.000	0.000	0.068	0.209	100.000
1986	Water Body	97.712	25.369	1.478	22.433	17.126	17.544	2.977	100.000	100.000
	Per_irrg_ Farm land	0.000	24.917	3.275	2.412	3.874	0.084	9.211	99.772	100.000
	Shrub land	0.000	3.456	57.766	0.363	3.739	0.418	5.250	99.920	100.000
	Seasonal Cultivated land	0.000	19.948	8.525	4.504	4.287	0.125	20.099	99.850	100.000
	Degraded land	0.045	23.058	24.721	54.472	69.969	0.251	56.398	99.668	100.000
	Active volcanic Area	2.243	1.633	3.960	1.473	1.395	81.579	0.626	99.961	100.000
	Grass land	0.000	0.203	0.127	14.344	9.609	0.00	5.371	99.572	100.000
	Class Total	100.00	100.00	100.00	100.00	100.0	100.00	100.00		
	Class Changes	2.288	78.083	42.234	85.656	18.421	30.031	79.901		
	Image Difference	**301.301**	**-11.130**	**-38.083**	**-10.224**	**111.696**	**136.512**	**-49.870**		

Table 4.1. 1973-1986 Percent base LU/LC changes

		1973								
		Water body	Per_irrig_ Farm Land	Shrub land	Grass Land	Degraded land	Active Volcanic Area	Seasonal Cultivated land	Row Total	Class Total
1986	Unclassified	0	0.39	0.29	0	0	0	0.06	0.74	353.1
	Water body	7.08	6.92	2.91	3.41	4.81	1.36	2.57	29.06	29.06
	Per_irrig_farmland	0	6.79	6.45	0.37	2.62	0.01	7.94	24.18	24.23
	Shrub land	0	0.94	113.8	0.06	2.52	0.03	4.53	121.88	121.98
	Seasonal Cultivated land	0	5.44	16.79	0.69	2.89	0.01	17.33	43.15	43.21
	Degraded land	0	6.29	48.7	8.29	47.24	0.02	48.62	159.17	159.69
	Active Volcanic Area	0.16	0.45	7.8	8.22	0.94	6.35	0.54	16.46	16.47
	Grass land	0	0.06	0.25	2.18	6.49	0	4.63	13.61	13.67
	Class Total	7.24	27.27	197.01	15.22	67.52	7.78	86.21		
	Class Changes	0.17	20.47	83.2	13.04	20.28	1.43	68.88		
	Image difference	21.82	-3.03	-75.03	-1.56	92.17	8.69	-42.99		

Table 4.2 1973-1986 LU/LC change in area base (km^2)

4.2.2 Change detection from 1986-2003

Phase I. 1986 - 2003 Percent base LU/LC change

The lake water body has increased by 33.938 % from 1986 to 2003, which is estimated to be 9.86 Km^2 area. The major land uses that were inundated due to the lake expansion are the active volcanic area which accounts for about 22.493% of its area in 1986 (i.e. about 3.68 km^2 area). Generally the lake expansion inundated the following areas from 1986-2003: 1.47 km^2 of Irrigated areas, 0.5 km^2 of Shrub lands, 0.07 km^2 of grass lands, 2.36 km^2 of degraded areas, 3.68 km^2 of active volcanic areas and 1.83 km^2 of seasonal crop lands.

Phase II. 1986-2003 LU/LC change in area base (km^2)

In general, along with the lake expansion the degraded and active volcanic lands have expanded significantly. This happens because of the practice of charcoal preparation and clearing of natural vegetation for preparation of farmland in the catchment.

The active volcanic lands expanded by 2.12 km^2, grassland by 20.98 km^2, and perennial irrigated farm lands by 16.66 km^2.

Relatively speaking, the lake expansion was smaller between 1986 - 2003 than between 1973 - 1986. This could be due to the various mitigation measures applied to control the lake expansion.

		1986								
		Water body	Perennial irrg_farm land	Shrub land	Seasonal cultivated land	Degraded land	Active volcanic area	Grass land	Row Total	Class Total
Unclassified		0.000	0.080	0.073	0.084	0.406	0.094	0.195	0.241	100.00
2003	Water Body	99.838	6.032	0.408	4.224	1.480	22.497	0.486	100.00	100.00
	Perennial irrg_ farm land	0.000	74.887	1.500	25.824	5.942	0.457	0.941	99.885	100.00
	Shrub land	0.000	7.997	81.617	25.440	9.796	19.683	0.782	99.910	100.00
	Degraded Land	0.000	5.668	9.181	15.767	47.473	1.688	36.959	99.916	100.00
	Active volcanic area	0.162	3.282	4.875	0.917	1.375	55.198	0.332	99.899	100.00
	Seasonal cultivated land	0.000	0.254	0.684	14.285	18.807	0.035	39.606	99.903	100.00
	Grass Land	0.000	1.801	1.661	13.459	14.720	0.352	20.700	99.918	100.00
	Class Total	100.00	100.00	100.00	100.00	100.00	100.00	100.000		
	Class charge	0.162	25.113	18.383	85.715	52.527	44.802	79.300		
	Image difference	33.938	68.541	7.879	-1.937	-36.937	12.947	152.963		

Table 4.3. 1986-2003 Percent base LU/LC change

		1986								
2003		Water body	Per_irrig_ Farmland	Shrub land	Seasonal Cultivated land	Degraded land	Active Volcanic Area	Grass land	Row Total	Class Total
	Unclassified	0	0.02	0.09	0.04	0.65	0.02	0.03	0.83	346.14
	Water body	29	1.47	0.5	1.83	2.36	3.68	0.07	38.9	38.9
	Per_irrig_farmland	0	18.2	1.83	11.21	9.47	0.07	0.13	40.92	40.97
	Shrub land	0	1.94	99.6	11.04	15.62	3.22	0.11	131.54	131.65
	Degraded land	0	1.38	11.2	6.84	75.69	0.28	5.07	100.46	100.54
	Active Volcanic Area	0.05	0.8	5.95	0.4	2.19	9.03	0.05	18.46	18.48
	Seasonal Cultivated land	0	0.06	0.83	6.2	29.99	0.01	5.43	42.52	42.56
	Grass land	0	0.44	2.03	5.84	23.47	0.06	2.84	34.67	34.7
	Class Total	29.04	24.31	122.04	43.4	159.43	16.36	13.72		
	Class Changes	0.05	6.1	22.43	37.2	83.75	7.33	10.88		
	Image difference	9.86	16.66	9.62	-0.84	-58.89	2.12	20.98		

Table 4.4.1986-2003 LU/LC change in area base (km^2)

4.2.3 Land use/ Land cover classes

To evaluate the effect of the land use/land cover change on the expansion of Lake Beseka, comparison has been made between the years1973-1986 and 1986-2003. All the land use/ land cover types show significant changes. In general, the water body increased by 31.68 km^2 (335.241%),while perennial irrigated farm land, grass land, active volcanic area and degraded land showed increment by 13.63 km^2 (57.21%), 19.42 km^2 (142.74%), 10.81 km^2 (124.643%) and 33.28 km^2 (99.575%), respectively. On the contrary, the seasonal cultivated land and the shrub land decreased by 43.83 km^2 (51.807%) and 33.37 km^2 (30.04%), respectively, between the year 1973 and 2003.

In the past, the majorities of the local people in the catchment area were pastoralists and earn their living mainly on animal rearing and moving from place to place after their cattle looking for grazing land and water. Construction of permanent houses, practice of charcoal preparation and clearing of natural vegetation for preparation of farmland existed are very recent phenomena in the area due to the fact that, since the last few years the living style of the local people is changing as a result of population pressure. The establishment of the two state farms (Abadir and Nura Hira) and the enlargement expansion of the two towns (Metehara and Addis Ketema) have also affected the way of living of local people. More than half of the population has settled and start permanent farming practice that leads to the cutting of trees for construction and clearing of natural vegetation for preparation of farmland. Other recent land use practices in the Beseka area are quarrying and sand dredging, fishing, and collection of firewood and charcoal production. As it is observed, charcoal and fire wood market is increasing tremendously.

Abadir Farm, part of the Metehara Sugar Plantation lies immediately to the south of the lake on the left bank of River Awash. The farm has undergone significant changes in its extent of irrigated area, cropping pattern, and irrigation method and system layout since its establishment around 1968. The continuous change in the lake level and areal extent has been attributed to the unsatisfactory irrigation and drainage practices at the two farms since about three decades. Almost all the previous studies have laid the blame for the lake water level rise on these farms and put great emphasis on Abadir Farm. In turn, the lake water affects part of the sugar plantation that is located on the left bank of Awash River. The impact of the lake on the farm can be grouped in to two: loss of annual income due to total inundation of part of the sugar cane plantation and reduction of the cane yields either by making mechanical operation impossible and/or by affecting the growth of cane in the field.

CHAPTER FIVE

5. TREND ANALYSIS OF LAKE LEVEL RISE AND AREAL EXPANSION

5.1. Lake Level Rise

The reasons for lake level rise include inflow of irrigation water from the Abadir Farm southeast of Beseka (Halcrow, 1978), underground water system discharge into the lake, and inflow from the hot springs southwest of Beseka that might have been changed due to tectonic activity. In addition, water balance studies indicated that discharge of ground water might also contribute to the increase in water level.

In this study, the lake level records have been plotted in time series order in order to examine the presence of trend and utilize the relationship for prediction of future rise in lake level (figure 5.1).

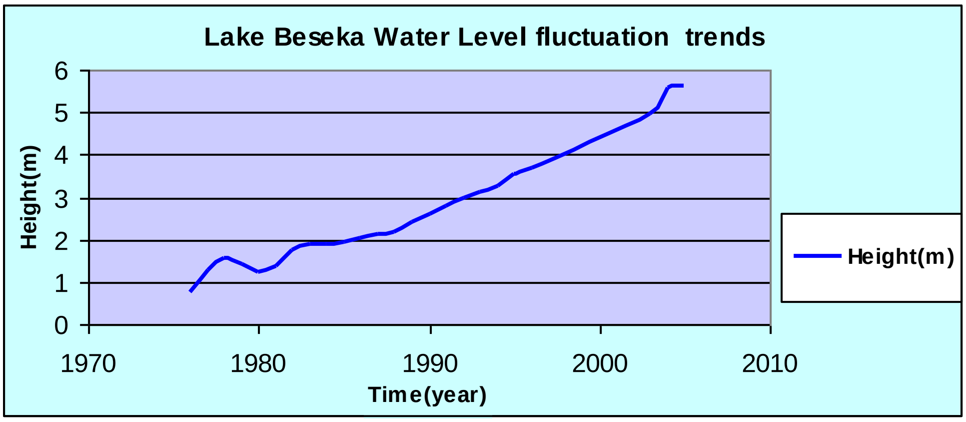

Figure 5.1 Lake Level rises as measured by the Hydrology Department of Ministry of Water Resources.

The lake level record of the period 1976 – 2005 plotted as a trend line in figure 5.1 may be considered representative of the last three decades and is used for prediction of future lake level rise in partial series condition.

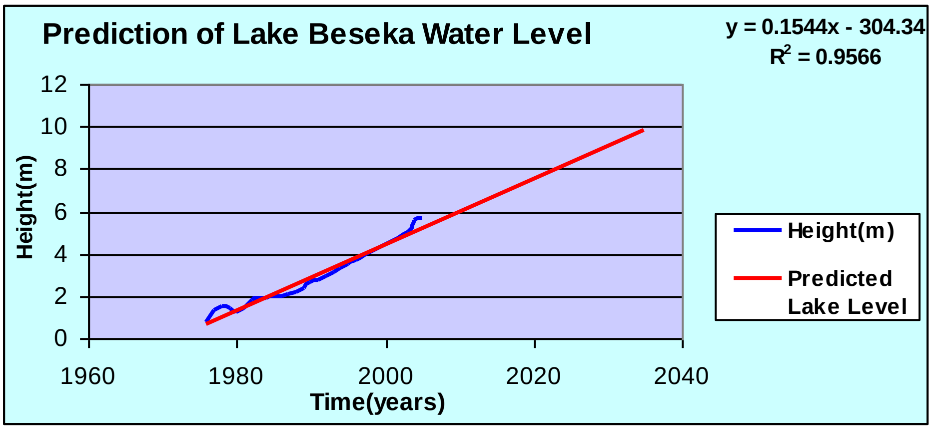

Figure 5.2 Lake level prediction of Lake Beseka based on 30 years of observation.

Based on the results of prediction (figure 5.2), it can be concluded that as a result of continuous rise in lake level and with no intervention measures, the lake water will start to flow towards river Awash via lowest points and finally will join it at its natural course, in the near future. Given the unsuitability of the Lake's water for irrigation and drinking purposes, this would be the worst scenario as many commercial farms and pastoralists are using Awash River. If the Lake water joins Awash River by its own (uncontrolled), the environmental damage that it would engender is believed to be very high, or at least too costly to recover.

5.2. Areal Expansion of the Lake

Lake Beseka shows a marked change in lake level and in areal extent among the rift valley lakes, and the change is considered to be due to non-climatic factors as shown earlier. The areal change in the lake can be described in terms of four periods between 1964-2003 (figure 5.3).

The first period was before 1964, the year which marked the beginning of the lake's abnormal expansion (Halcrow et al., 1979). This year also marked the time when the Abadir Farm (a sugar cane plantation south of Lake Beseka) and the

Metehara Sugar Estate east of the Lake, became operational (Tessema, 1998). Both the Abadir Farm and the Metehara Sugar Estate rely on the nearby Awash River for watering purposes.

According to MoWR (1999), integrated studies resulted that the main cause for the continuous lake level is the increment of the spring discharge flowing to Lake Beseka at the southwest edge. The increment of the discharge of the springs has been attributed to the hydraulic barrier increment at the eastern side of the lake due to excess irrigation water recharge, which highly decreases the groundwater flow under the lake.

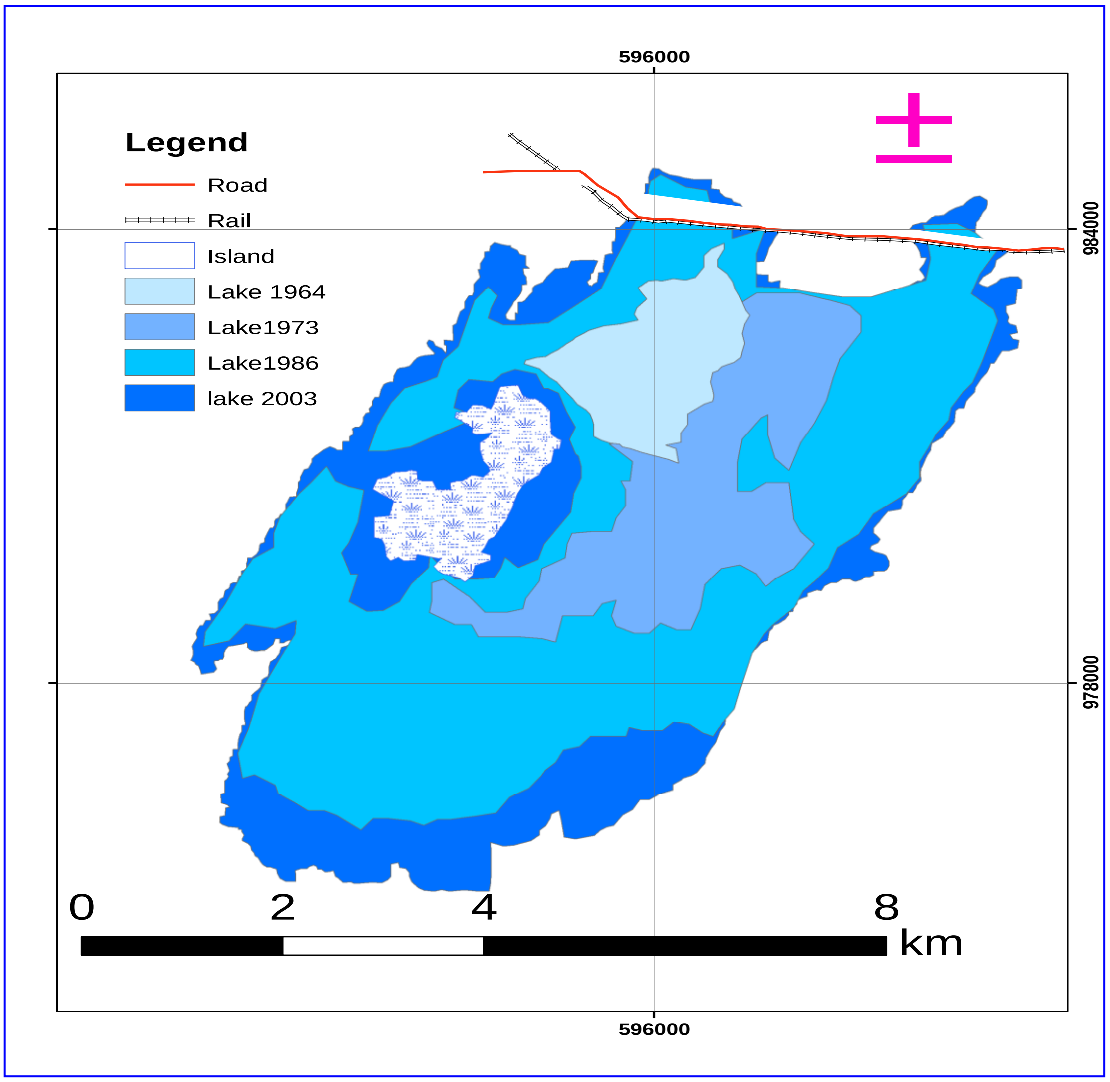

Figure 5.3 Evolution of Lake Beseka (manually digitized from false color composite of satellite images of years 1973, 1986 and 2003).

The second period (1964-1973) was characterized by gradual increase while the third period, (1973-1986) was characterized by continuous sharp increase.

As indicated in fig. 5.3, the third period can be considered to be the representative of the recent development with positive trend followed by sharp increase. As information obtained from Metehara Sugar Estate, in this period the irrigated farmland was highly intensified. On top of this, there were a significant land use/land cover changes in the Beseka's catchment.

The statistical analysis of areal expansion of Lake Beseka revealed that the surface area of Lake Beseka in 1973 was 6.55 Km^2. After thirteen years, the surface area of Lake Beseka was 31.55 Km^2. Again, after seventeen years, in the year 2003 the Lake surface area was 43.49 Km^2. Over all the image subtraction yielded the spatial extent of the Lake within 30 years is about 36.84 Km^2, which is very significant (see Annex VIII) and the associated graph, figure 5.3.

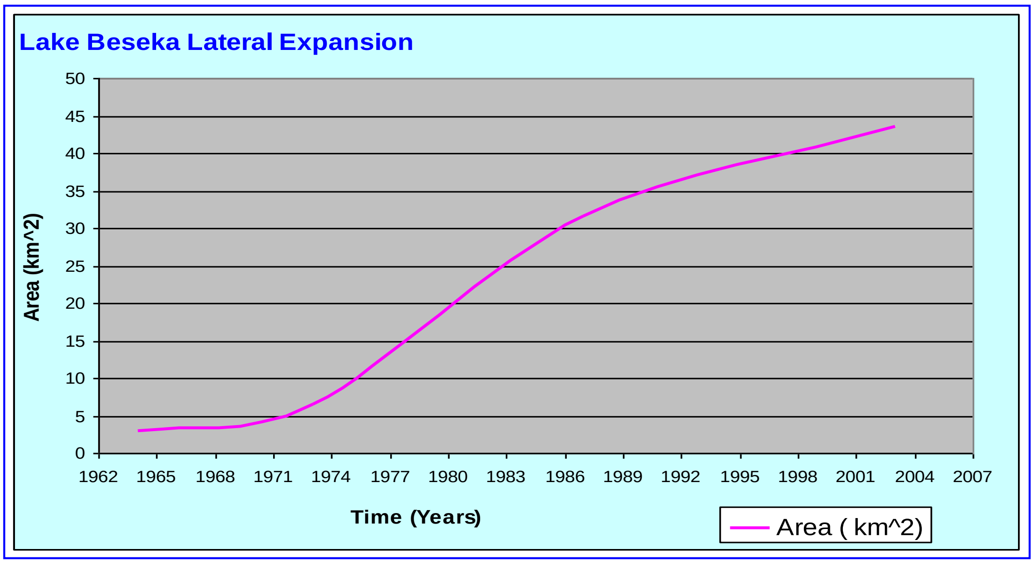

Figure 5.4. Lake Beseka areal expansion (constructed from its area of 1964,1973,19086 and 2003)

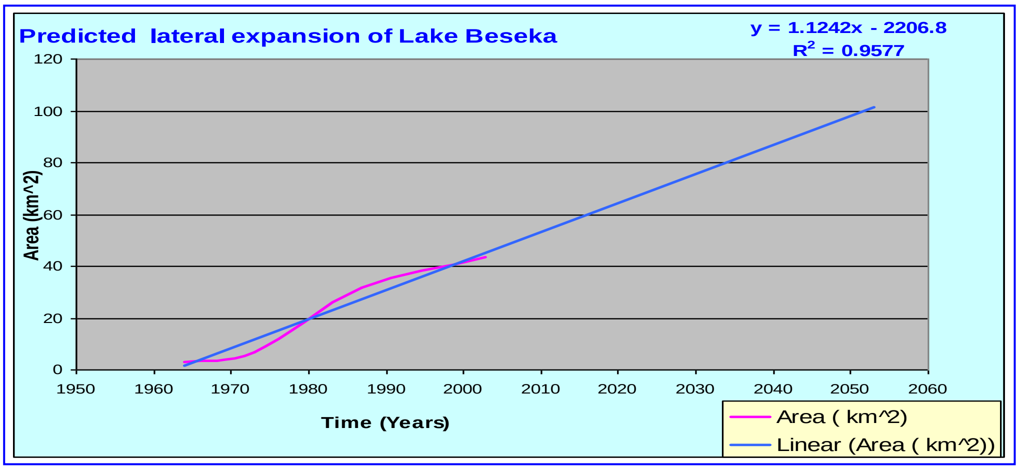

Figure 5.5 Predicted Lateral expansion of Lake Beseka (Area based)

Based on the results of prediction (see figure 5.5), in about 6 years time the saddle point that naturally exists adjacent to the lake and which assumes elevation 952.95 m.a.s.l will probably be overtopped. As a result of continuous rise in lake level and with no intervention measures, the lake water will start to flow towards river Awash via lowest points and finally will join it at its natural course. The surface elevation of the lake as of December 13, 2003 was about 950.70 m.a.s.l, which was then lower than the saddle point by 1.65 m.

CHAPTER SIX

6. ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACT OF THE EXPANSION OF LAKE BESEKA

The Beseka Lake expansion has imposed several problems on the inhabitants and institutions found within the vicinity of the Lake.

6.1 Negative Impacts

According to the MoWR (1999) some of the major negative impacts of the lake rise are:

6.1.1 Effects on existing infrastructures

A major highway and a railroad-Ethiopia's only access to the harbour in Djibouti-run along Lake Beseka northern shore. Due to the water level rise of Lake Beseka (Figure 6.1), railway and road authority have been forced to raise the rail line and the road several times and each rising cost millions of Ethiopian Birr. Though the road has been elevated recently, it is still threatened by ever increasing inundation.

Figure 6.1. Inundation of rail line and main road by Beseka Lake (Amare, 2005)

6.1.2 Impacts on the Metehara Sugar cane plantation

The growing Lake has already flooded parts of the Metahara sugar plantation south of Beseka. Inundation of the Metehara Sugar cane plantation results in a very poor sugarcane production due to inefficient mechanical operations caused by high water table and high sodium salt deposit.

Figure 6.2- A dam built on the southern shore of Lake Beseka to prevent further damage to the Abadir sugar cane plantation (adopted from Goerner, A., 2005).

If immediate remedial measures are not taken to stop the lake level rise, before the lake water unrestrictedly flows into Awash River, it will inundate the vast area of the sugarcane plantation, which would be great lose for the Metehara Sugar Factory.

6.1.3 Inundation of grazing land and wood land

In the early 1960s, the Lake surface was about 5 km^2 (MoWR, 1999). Now it covers about 41 km^2. This means about 36 km^2 of grazing land, active volcanic area, degraded and shrub land areas have been inundated during the last four decades (Fig.6.2) From this land 0.55 km^2 belongs to the Metehara Sugar Factory. This figure indicates that during the last four decades the local people had lost about 35.45 km^2 of their valuable land.

Fig 6.3Inundation of the surrounding grazing and woodland at Abadir side (Amare, 2005)

As a result, the local people were displaced and forced to move to other places in search of grazing land and watering point. Most of them moved into the near by Awash National park and presently causing irrecoverable damage to the park area.

6.1.4 Effects on the ecosystem

Because of high saline nature of the lake water and physical expansion and inundation of water into the terrestrial and wetland areas, the stability and functioning of this ecosystem were seriously affected. If the lake is to be left unchecked, it would continue to increase in its size, and spill over into the river Awash. Since the Lake water is very alkaline (PH=9.5) and saline (EC=6.3mS/cm) (Amare, 2005), mixing the lake water with the river water is therefore likely to affect the hydrochemistry of the river and the ecosystems down stream. Especially the Afar people whose livelihood is based on livestock rearing will be seriously affected as Awash River is their major watering point.

6.1.5 Causing public health problem

Expansion of the lake towards the Metehara town would create a favorable breeding site for disease vectors and will aggravate the infection rate of people by diseases such as malaria, bilharzias and Intestinal parasites. Hence, many of the residents of the vicinity are likely to be victims of various diseases.

6.1.6 Hindering the economic development of Metehara town

Lake Beseka is approaching the border of Metehara town and one could conclude that if immediate measure is not taken, Metehara town would ultimately be inundated.. However, simultaneous to the increment of the lake, no major investment activity is taking place in Metehara. As a result, the town has not benefited from the new investment policy of the country. Since investors would be frightened by the situation of the expansion of the lake, they would likely retreat from investing their capital in the town. This condition limits the development of the town. Any remedial action that would have been taken to stabilize the lake will therefore motivate the investors thereby indirectly benefits the town.

6.1.7 Causing social problem on the residents of the vicinity

Observing the continuous expansion of the lake, the residents of Metehara town and the permanent dwellers near the lake area are under serious psychological burden fearing that the town and the surrounding area may be inundated and many lives may be lost as a result. Besides, they expect that they may loose their property and may be disconnected due to the interruption of the road and the railway.

6.1.8 Impact on the Awash National Park

The Awash National Park faces a significant impact caused by the Beseka Lake level rise. The impact of the Lake level rise on the park is mainly indirect. The expansion of the lake has inundated considerable area of grazing land and watering points of the surrounding pastoralists, namely Ker00u. These pastoralists are forced to look for alternative grazing and watering sites and they encroached into the park area. As a result, the park area has been pressurized and the stability of wild life and their habitat has been disturbed. In addition, the existence of wild and domestic animals in the same park may reduce tourist attraction and may also result in the transmission of communicable diseases between the wild and domestic animals. Moreover, the expansion of the lake has inundated considerable area of the Abadir sugar plantation. Hence, in order to compensate the lost land, the sugar factory has expanded its farm towards the park's occupation and imposed more pressure on the park as well.

6.2 Positive Impacts

Among the positive impacts, being located at the foot slope of the Mount Fentale, the scenery of the lake is very attractive. In addition, it harbors some species of fish, crocodiles, birds, etc. Its presence will be beneficial if and only if the inflow and out flow of the lake water is balanced and further expansion is controlled.

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSIONS

The major conclusions of the present study are:

1. According to the lake water balance modeling

- Rate of open water evaporation on the average is about 75.66 Mcm/year which is about two times higher than that of runoff from effective catchment together with rainfall on the surface of the lake (37.24 Mcm /year.
- On average, change in storage is about 2.96 Mcm /year.
- The ground water inflow to the lake on average is about 36.15 Mcm/year excluding Abadir farm releases.
- The Abadir farm release to the lake on average condition is about 3.54 Mcm/year.
- Surface water sources are not significantly influencing the lake level rise. Therefore, it can be concluded that the rise in lake level might have been influenced by sub-surface inflow, which includes spring discharges and deep groundwater source.

- The main reason from time to time increment of the springs discharge are considered to be the hydraulic barrier increment from the eastern side of the Lake due to excess irrigation water which highly decreases the ground water flow under the Lake.

2. The LU/LC change detection analysis revealed that the lake body has increased by 21.82 km^2 (301.301%) between 1973 and 1986, and by 9.86 km^2 (33.938%) between 1986 and 2003. In general, between 1973 and 2003, the lake has expanded by about 31.68 km^2 (335%).The land use/land cover of the area dramatically changed in the last three decades. This change has a direct effect on the expansion of the lake. Vegetation cover (shrub land) had been reduced by 65.41 km^2 (30%). This in turn affects the runoff yielded from the catchment entering into the lake. Unlike vegetation cover, degraded land had increased by 33.28 km^2 (89.575%), which increases runoff entering into the lake. The other important land use that has been significantly changed in the last three decades is irrigation farmland which increased by about

13.63 km^2 (57.411%). In general, the result of the research indicated that the land use/land cover change of the area has an additive effect on the lake's areal expansion.

As a result of continuous rise in lake level and with no intervention measures, the lake water will start to flow towards river Awash via lowest points and finally will join it at its natural course in about 6 years of time.

3. The Beseka lake level rise has considerable socio economic impacts on the inhabitants and institutions found within the vicinity of the Lake. Institutions that fall within the impact of the lake are Awash National Park, Ethio- Djibouti Railway, the Metehara Sugar Estate and the Road found within the area. The Metehara town and pastoralists inhabiting the surrounding areas of the lake are also victims of the effects brought about by the lake level rise.

7.2 RECOMMENDATIONS

The rise in lake level certainly continues and further encroachment of useful agricultural land and inundation of the railway line and the main highway will still be the major problems that undoubtedly require appropriate remedial measures in the very near future. The following recommendations are forwarded with regard to remedial measures and monitoring of the lake.

- Intensive abstraction of water from the lake water so that significant draw down in lake level could be brought about and reclamation of previously submerged agricultural and grazing land is made practical besides arresting the lake level growth. This could be realized by abstracting environmentally acceptable magnitude of lake water and blending it with Awash River water via conveyance system. The blending criteria are drawn based on the water quality data of Awash River and guidelines for interpretation of water quality for irrigation and drinking. To keep the water quality of Awash River downstream in the same water class for both drinking and irrigation the maximum tolerable controlled discharge to Awash River is calculated 2% of Awash flow at any time for the lake and 8% the intercepted groundwater

- Interception of the groundwater and discharging it to river Awash in such a way that environmental requirements are strictly met. This could be recommended as future area of study and research, which highly minimizes the degree of hazard in light of environmental issues.

- Monitoring of the lake level, lake water regimes and the ground water sources is of paramount importance in the implementation and operational phases of remedial measures. So, monitoring is better maintained at higher standards in order to fulfill future conditions of realization of the proposed remedial measures that will be undertaken by concerned institution. It is advisable to install automatic level recorder side by side with the staff gauge so that discontinuity in the data series and human error in observation could be reduced to the minimum possible.

- The effect of the land use/land cover change on the expansion of Lake Beseka is very high. As a result the following important recommendations have been forwarded
    - A campaign of afforestation and contour building in sloppy area
    - Educate the local people on proper land management
    - Cut off the trend of movement of cattle towards the protected area, which is created by the population pressure and changing of grazing land to farmland
    - Serious controlling system has to be established to control the alarmingly increasing charcoal and fire wood market.

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9. ANNEXES

Annex I

Element: Monthly Mean Rainfall (mm)

Region: Shoa

Station: Metehara

year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1976	9.2	12.6	57	53	52	9	123	147	31	8	30	3
1977	110	46	7	68	88	103	75	70	18	223	18	2
1978	54	106	31	6	16	4	99	90	52	34	5	30
1979	76	43	51	5	59	42	135	75	53	14		3
1980	10	5	5	47	15	30	132	183	34	7	12	5
1981	15	1	130	72	3	2	174	190	62	11	5	6
1982	32	67	68	21	101	4	101	304	36	92	36	11
1983	6	49	64	49	93	21	139	143	18	8	8	1.5
1984	5.1	24	13	68	63	33	66	69	71	5.2	9.0	8.0
1985	6.3	15.2	29.6	76.6	104.5	12.0	166.7	153.7	41.9	4.4	0.5	5.1
1986	42.1	41.6	43.2	25.9	13.0	51.8	64.3	67.1	36.5	4.0	5.0	7.0
1987	9.7	24.1	71.2	78.0	74.8	51.2	53.6	110.4	8.0	2.8	5.0	2.3
1988	13.6	29.6	11.3	23.7	7.8	11.3	156.5	136.1	104.3	18.0	7.0	11.9
1989	31.2	28.0	104.8	101.3	7.5	82.1	48.7	92.7	28.2	5.6	9.0	12.7
1990	12.3	220.8	58.1	62.9	1.8	30.9	146.4	76.9	82.4	2.1	6.2	2.0
1991	6.0	54.3	56.1	46.7	53.3	15.4	137.0	132.0	49.6	11.7	2.1	1.6
1992	25.8	50.3	2.0	75.8	16.8	62.4	90.0	157.6	62.2	49.6	5.7	2.3
1993	43.8	59.5	1.5	139.6	57.3	23.7	101.4	103.7	41.6	21.9	31.0	56.9
1994	5.0	9.0	6.5	21.4	55.4	38.6	248.4	131.6	39.6	0.1	12.7	1.9
1995	1.0	43.5	81.9	44.0	10.5	28.5	47.3	144.1	57.7	0.5	1.0	2.0
1996	27.6	40.0	97.3	35.1	80.5	26.5	205.1	100.5	52.6	1.6	7.5	5.0
1997	29.7	4.0	12.6	44.3	11.5	35.1	139.7	53.8	20.4	112.4	14.6	3.0
1998	0.8	18.1	76.6	34.2	14.9	4.7	78.2	135.6	54.0	78.0	20.0	7.0
1999	16.8	31.0	73.6	6.2	15.9	16.7	136.1	151.2	16.4	76.2	2.2	6.0
2000	8.5	9.0	1.8	20.7	36.9	29.6	135.9	152.7	46.8	47.3	11.9	9.4
2001	0.9	13.6	92.7	20.4	12.7	20.2	154.8	82.8	15.3	7.1	6.0	1.6
2002	2.6	35.7	73.3	19.3	9.3	10.2	43.0	80.8	16.8	7.0	5.0	21.2
2003	4.6	17.5	33.6	13.7	8.1	29.5	118.9	186.0	31.0	4.0	3.2	15.7
2004	35.1	3.2	80.6	142.4	52.0	21.2	85.3	123.9	39.3	15.9	4.5	10.0
2005	19.3	40.1	48.0	51.6	75.5	35.7	146.4	138.4	21.6	12.0	5.2	4.0
Mean monthly	**22.0**	**38.1**	**49.4**	**49.1**	**40.3**	**29.5**	**118.3**	**126.1**	**41.4**	**29.5**	**9.9**	**8.6**

Annex II

Element: Monthly Mean Evaporation (mm/day)

Region: Shoa

Station: Metehara

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1976	6.6	7.4	7.5	7.2	7	8.7	6.5	5.6	6.2	6.8	5.9	6
1977	5	6	7.6	6.6	6.3	7.6	7.1	6.6	6.6	6.6	5.3	5.6
1978	6.4	5.6	6.6	8.1	7.9	8.9	6.4	6.4	6	6.9	6.6	6.2
1979	4.7	6.4	6.7	7.5	6.3	7.9	7.5	5.8	6.3	6.5	6.9	6.2
1980	6.2	7.5	8.5	7.1	7.9	8.2	6.2	5.5	7.4	6.6	6.6	6.5
1981	6.3	7	5.8	5.7	7.2	7.7	6.7	5.6	5.4	6	6.4	6.7
1982	6	5.5	6.9	6.5	7.3	7.5	7	7.6	6.4	6.2	5.3	5.4
1983	6.5	6	8.2	6.1	7	7.9	7.4	6.2	5.8	6.7	6.4	5.8
1984	6.2	7.7	9.3	8.9	7.9	7.7	7.5	6.6	6.9	8.5	8.4	7
1985	12.6	13.6	16.4	8.9	8.9	13.7	7.4	6.4	7.3	11.4	12.2	11.5
1986	11	10.2	10.8	11.4	12.7	9.5	7.5	8.2	9	12.6	15.1	10.9
1987	12.6	14.8	9.9	9.8	9.5	12.1	11.2	8.7	11.2	14.6	14.3	10.3
1988	7.4	9.5	12	9	16.9	11.8	8.4	5.2	5.2	8.5	9.7	8.4
1989	9.3	8.7	9	5	9.9	11	9.1	5.2	7.5	9.9	12.3	7.9
1990	10.4	4.9	6.1	7.7	12.1	14.5	8.7	8.1	7.5	11.1	10.9	9.8
1991	10.1	7.8	8.8	8	9	10.4	7.9	5.2	6.1	9.6	9.9	8.5
1992	7.1	5.9	10.8	6.9	9.2	10.7	8.4	5.2	5.9	7.7	8.4	7.6
1993	6.8	5.3	10.7	7.6	6.6	10.5	8.2	7.2	7.7	8.5	9.6	9.1
1994	8.9	9.5	9.5	9.4	10.1	11	6	5.6	5.8	9.4	7.4	7.6
1995	8.4	8.8	6.7	7.1	10.9	11.1	8.7	6.5	6.1	11	9.7	8.2
1996	7.1	9.9	7.4	7.2	7.3	9.2	7.3	6.2	6.6	9	7.8	9.9
1997	7.1	9.7	9	7.6	10.1	9.2	6.6	5.8	7.1	5.4	4.1	5.3
1998	4.4	5.1	5.9	8.6	9	9.9	8.6	4.9	4.7	4.9	6.8	6.8
1999	8	9.8	5.9	9.3	9	7.5	5.5	4.4	5	5.4	6.2	7.6
2000	8.3	8.6	9.7	8.5	7.9	8.8	7.2	5	4.9	4.4	5.6	5.7
2001	5.2	7.1	5.6	6.9	7.9	8.1	5.3	4.3	5.2	7.9	7.9	6.8
2002	5.5	7.9	6.5	8.3	9.1	7.8	8.3	6.7	7.7	8.1	7.4	6.5
2003	5.3	8.1	7.9	8.6	9.2	9.5	6.4	4.2	4.3	8.1	7.6	5.3
2004	5.0	6.8	7.9	5.2	9.1	8.9	8.2	6.9	6.7	8.2	9.1	8.6
2005	7.3	9.0	8.5	9.0	6.0	8.8	5.3	4.9	6.6	9.8	8.7	8.2
Mean (monthly)	**7.39**	**8.00**	**8.40**	**7.79**	**8.84**	**9.54**	**7.41**	**6.02**	**6.50**	**8.21**	**8.28**	**7.53**

Annex IIIA

Element: Monthly Mean Max. T°C

Region: Shoa

Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976	30.7	33.1	34.8	34.6	34.4	37.2	32.8	30.8	33.2	33.3	30.5	31
1977	29.7	29.1	33.6	34.4	34.9	35.5	33.4	32.6	34.7	32.5	29.5	30.5
1978	30.9	31.3	33.3	34.9	36.7	37.1	31.4	31.9	32.9	32.2	31.2	29.2
1979	27.8	30.9	33	36.7	33.7	34.4	33.1	32.6	34.1	33.1	32.4	30.6
1980	30.1	33.2	35.1	33.7	35.6	37.2	31.9	32.3	34.2	33.9	32.3	30.5
1981	31.9	32.2	29.8	35.6	34.1	36.3	32.4	30.7	31.6	32.2	31.1	29.3
1982	30.2	31	33.4	34.1	32.9	36	33.4	31.1	32.7	30.1	29.9	29.9
1983	29.2	30.2	32.7	32.9	34.2	35.8	34.2	33.8	33.2	32.9	30.9	29.7
1984	31.1	30.7	34.7	34.2	34.7	34.4	33.8	30.4	32.9	33.1	31.9	29.9
1985	32.2	31.7	35.5	33.5	34.5	36.7	32.7	31.4	33.7	33.9	32.6	30.8
1986	30.9	33.6	34.4	34.4	36.5	34.9	32.8	33.6	34.5	33.9	33.1	31.1
1987	30.3	33.6	33.6	33.6	33.7	36.9	36.4	33.3	35.7	34.7	33.1	32.1
1988	31.0	33.8	35.5	35.5	37.3	37.1	32.2	31.7	32.7	33.2	31.7	30.3
1989	29.7	30.7	33.4	31.1	35.8	36.0	32.6	33.2	33.7	34.2	32.4	29.9
1990	31.2	29.6	30.9	32.7	37.0	37.7	32.7	32.7	33.6	34.1	32.7	30.8
1991	32.6	32.2	34.6	34.1	35.0	36.7	32.3	31.3	33.9	33.8	31.8	31.0
1992	30.4	29.8	35.1	35.3	35.9	36.6	32.8	30.9	32.3	32.7	31.8	31.5
1993	30.2	28.9	34.9	33.5	33.6	36.8	33.1	33.1	34.2	33.9	32.7	31.4
1994	31.4	33.0	35.3	36.5	36.3	36.3	32.1	31.7	32.3	33.5	31.0	30.1
1995	31.1	33.4	32.4	34.8	36.9	37.7	33.2	32.5	33.5	34.3	33.0	32.5
1996	31.6	34.2	34.4	34.4	34.3	34.7	32.3	32.4	34.1	34.3	31.9	31.1
1997	31.3	32.1	35.3	34.1	36.8	36.3	33.1	33.3	36.0	31.6	30.3	30.4
1998	30.1	32.9	33.9	36.9	37.2	38.1	34.3	31.5	33.8	32.9	32.3	31.0
1999	32.0	34.8	32.8	36.3	37.2	36.8	31.9	32.0	33.7	31.9	31.3	30.4
2000	31.8	33.2	35.1	35.7	36.8	37.3	33.2	31.5	33.7	32.7	32.0	30.9
2001	30.1	32.8	33.7	35.9	37.8	36.4	33.0	31.3	34.9	34.8	32.7	31.7
2002	30.9	33.9	34.5	36.3	38.3	37.8	36.6	33.6	35.4	35.3	33.5	31.4
2003	31.3	34.8	35.6	35.8	38.1	36.8	32.0	31.6	32.6	35.2	33.1	30.9
2004	32.3	32.4	34.1	33.4	37.8	36.9	33.0	33.1	34.7	33.4	32.5	31.2
2005	31.6	35.0	33.7	35.8	34.5	36.5	32.2	33.4	35.0	34.9	33.2	31.7
Mean (monthly)	**30.9**	**32.3**	**34.0**	**34.7**	**35.8**	**36.5**	**33.0**	**32.2**	**33.8**	**33.4**	**31.9**	**30.8**

Annex IIIB

Element: Monthly Mean Min. T°C

Region: Shoa

Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976	12.3	17.1	17.9	18.6	19.7	21.4	20.1	18.6	18.4	15.3	14.1	13.6
1977	18.4	14.3	17.7	18.6	19.3	21.4	21	19.8	19.3	18.8	15.2	14.2
1978	12.9	16	18.7	18.5	20.4	21.7	19.6	19.1	18.5	16.5	13.7	14.1
1979	16.9	13.6	16.9	17.8	18.8	20.8	19.8	19.5	19.2	15.7	11.2	14
1980	14.1	16.8	19.8	19.4	19.2	22.7	20.6	19.6	19.4	16.5	14.7	11.3
1981	13.3	13.1	17.7	17.7	17.5	20.8	20.5	19	18.6	15	12.5	11.3
1982	16.6	18.1	17.3	18.2	18.2	20.4	20.3	19.1	18.4	15.1	15.6	15.4
1983	13.5	18.1	20.2	19.8	20.1	20	20.7	20.2	19.5	15.5	12.8	15.8
1984	11.1	11.2	15.9	18	19.3	20.6	19.4	20.1	18.3	15	15.1	13.7
1985	12.8	13.9	18.0	18.7	18.4	20.8	18.4	17.8	18.0	15.5	13.3	12.4
1986	9.8	18.4	17.6	19.9	19.8	20.9	19.4	19.7	18.6	15.6	13.8	13.6
1987	13.6	15.0	19.3	17.2	18.7	22.9	22.2	20.3	20.2	17.8	12.7	13.6
1988	16.7	18.8	17.9	19.9	19.1	22.3	20.6	19.5	19.4	16.7	10.0	12.2
1989	13.1	15.9	17.8	18.7	16.0	19.7	19.9	19.2	19.0	15.2	14.5	18.0
1990	14.7	18.8	17.6	16.9	20.8	22.6	19.4	19.9	19.9	15.1	14.7	12.2
1991	16.4	18.2	19.5	18.7	19.2	21.7	20.4	19.8	19.5	15.7	12.8	13.6
1992	16.9	19.1	20.5	20.3	19.8	21.5	20.3	19.9	18.6	16.8	15.0	16.8
1993	13.4	16.3	15.5	19.7	19.4	21.9	20.3	20.3	20.6	18.3	14.3	12.4
1994	11.9	14.8	20.1	20.8	19.9	21.8	19.6	19.5	18.5	15.4	14.3	13.0
1995	12.3	17.4	18.6	19.7	19.8	21.1	21.2	20.0	19.0	17.0	13.2	17.1
1996	17.7	15.2	20.1	19.3	19.7	21.4	20.2	20.1	20.0	15.4	13.4	11.7
1997	16.0	12.8	19.1	19.5	19.5	20.6	20.1	20.4	20.1	18.7	18.6	14.4
1998	18.1	19.6	20.1	20.4	21.1	23.2	21.4	20.0	20.3	17.8	12.6	10.0
1999	14.1	14.5	18.9	18.7	19.5	21.1	18.9	19.2	19.6	17.6	12.6	12.1
2000	12.1	12.1	16.5	19.3	20.7	22.4	19.8	19.7	19.7	15.9	14.7	13.0
2001	13.4	14.8	18.9	18.2	21.0	22.3	20.0	20.1	18.6	17.9	13.9	14.3
2002	16.6	15.7	20.1	19.9	20.5	22.3	21.8	20.0	19.1	17.7	14.3	18.0
2003	16.0	17.1	19.2	20.5	19.2	21.2	20.4	19.6	20.0	16.3	16.0	14.3
2004	18.2	15.4	16.1	19.3	18.3	21.9	19.6	20.6	19.9	16.7	15.5	15.8
2005	15.4	15.6	19.3	18.6	20.2	21.7	20.3	20.0	20.8	16.2	14.5	10.5
Mean (monthly)	14.6	15.9	18.4	19.0	19.4	21.5	20.2	19.7	19.3	16.4	14.0	13.7

Annex IVA

	Maximum Monthly Mean
Element	**Relative Humidity In %**
Region	**Shoa**
Station	**Metehara**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean (yearly)
1976	94	90	90	89	89	78	84	89	88	89	93	90	**88.58**
1977	87	87	84	85	85	78	82	82	88	92	94	90	**86.17**
1978	93	93	92	87	85	83	83	84	83	85	84	87	**86.58**
1979	86	85	85	85	83	82	82	82	84	85	83	84	**83.83**
1980	83	82	82	82	82	80	79	80	81	82	83	82	**81.50**
1981	81	81	80	80	83	80	81	82	82	81	81	81	**81.08**
1982	82	81	80	79	79	80	78	79	80	79	81	80	**79.83**
1983	80	79	80	79	80	78	78	78	79	80	79	80	**79.17**
1984	80	80	77	78	78	77	78	77	79	77	77	78	**78.00**
1985	77	76	78	79	78	76	77	76	80	79	82	92	**79.17**
1986	81	83	87	83	90	74	81	67	86	75	72	96	**81.25**
1987	77	71	85	85	81	67	69	82	76	73	72	75	**76.08**
1988	81	84	69	78	64	65	76	86	82	81	89	78	**77.75**
1989	81	71	65	82	75	79	80	46	50	79	35	84	**68.92**
1990	80	92	93	91	75	64	81	78	85	77	73	73	**80.58**
1991	78	82	81	86	84	64	80	84	84	80	77	81	**80.08**
1992	84	90	76	86	91	78	80	83	82	79	76	40	**78.75**
1993	83	93	80	86	87	69	81	80	81	85	80	82	**82.25**
1994	82	73	73	78	77	74	80	85	52	34	45	43	**66.33**
1995	80	81	91	87	80	73	79	84	86	77	78	87	**81.92**
1996	87	77	85	89	89	78	84	85	83	81	85	81	**83.67**
1997	85	79	79	85	78	83	85	83	81	92	92	86	**84.00**
1998	88	85	87	81	78	63	77	85	83	88	80	78	**81.08**
1999	78	70	84	73	72	69	85	88	83	92	84	81	**79.92**
2000	78	77	72	73	72	65	82	81	96	86	88	89	**79.92**
2001	83	84	86	81	81	69	82	84	86	77	74	78	**80.42**
2002	80	75	80	79	67	66	69	79	86	78	71	81	**75.92**
2003	82	74	73	77	74	76	79	82	83	78	75	83	**78.00**
2004	88	77	76	88	71	69	80	80	81	83	79	82	**79.50**
2005	86	83	86	83	86	74	82	83	79	74	78	83	**81.42**
Mean (monthly)	**81.3**	**80.2**	**80.5**	**81.5**	**78.5**	**72.4**	**78.8**	**80.6**	**81.0**	**78.4**	**78.0**	**80.2**	**79.3**

Annex IVB

Element	**Minimum Monthly Mean Relative Humidity In %**
Region	**Shoa**
Station	**Metehara**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean yearly)
1976	34	36	29	31	33	29	36	40	34	29	34	32	**33.08**
1977	44	36	33	31	30	30	36	34	25	29	28	26	**31.83**
1978	22	30	29	23	26	27	38	34	29	27	29	35	**29.08**
1979	46	37	33	26	26	26	28	29	27	24	21	30	**29.42**
1980	34	27	26	25	18	21	29	31	28	23	26	27	**26.25**
1981	28	29	37	33	25	22	27	34	30	20	23	25	**27.75**
1982	34	31	26	26	26	21	24	35	26	26	29	33	**28.08**
1983	30	34	16	23	24	19	23	34	22	20	23	29	**24.75**
1984	24	19	21	20	21	18	18	35	20	17	29	25	**22.25**
1985	22	25	31	25	19	31	29	34	31	28	23	33	**27.58**
1986	33	34	36	41	40	39	39	18	39	30	26	32	**33.92**
1987	34	28	42	40	40	34	30	41	38	26	27	30	**34.17**
1988	41	36	28	34	28	28	44	46	49	32	25	30	**35.08**
1989	34	41	45	52	35	39	49	46	50	34	35	48	**42.33**
1990	37	56	53	43	30	28	42	43	51	33	31	27	**39.50**
1991	31	40	38	37	45	26	45	51	45	31	29	32	**37.50**
1992	42	52	38	53	46	39	42	47	41	39	33	40	**42.67**
1993	48	52	30	45	44	29	38	43	43	40	30	29	**39.25**
1994	24	25	29	35	35	32	34	52	48	29	43	34	**35.00**
1995	30	35	47	44	36	32	44	48	44	36	36	45	**39.75**
1996	39	28	45	46	47	48	50	51	46	36	37	33	**42.17**
1997	42	35	38	48	39	47	49	47	44	57	52	41	**44.92**
1998	49	52	46	39	35	29	43	50	48	43	32	26	**41.00**
1999	30	20	39	36	36	33	48	46	46	48	32	33	**37.25**
2000	27	27	26	34	31	29	42	50	48	42	43	40	**36.58**
2001	43	41	41	37	37	34	42	51	42	30	26	34	**38.17**
2002	41	28	37	34	29	30	30	44	38	26	25	48	**34.17**
2003	40	31	29	39	27	30	44	55	51	30	31	33	**36.67**
2004	42	31	33	46	28	33	40	44	45	35	33	43	**37.75**
2005	39	30	45	37	47	33	47	53	44	27	27	26	**37.92**
1999	21	30	22	19	16	32	39	32	28	26	31	33	**27.42**
2000	24	22	21	21	17	29	38	36	32	32	31	38	**28.42**
2001	27	48	32	39	25	30	31	33	30	25	24	35	**31.58**
2002	34	35	41	33	28	31	32	34	32	26	32	28	**32.17**
2003	42	34	24	32	27	25	31	33	28	24	36	37	**31.08**
2004	30	23	22	22	24	17	21	35	28	23	31	28	**25.33**
2005	25	36	16	25	25	23	33	43	38	30	39	22	**29.58**
Mean (monthly)	**34.24**	**33.89**	**33.08**	**34.43**	**30.95**	**29.81**	**36.62**	**40.86**	**37.51**	**30.62**	**30.86**	**32.97**	**33.82**

Annex V

Element: Mean Monthly Sunshine Duration in Hours

Region: Shoa

Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976	9.5	9.4	9.1	9.0	8.2	8.5	6.5	6.5	7.5	8.2	8.4	9.3
1977	6.5	8.2	8.2	7.4	8.4	8.4	7.3	7.6	7.4	7.3	9.4	9.3
1978	9.4	7.6	8.3	8.5	9.1	8.4	6.5	7.6	8.1	8.2	9.1	8.4
1979	6.3	8.5	8.4	9.1	8.5	8.6	8.3	8.2	8.1	7.6	9.4	9.3
1980	9.4	8.3	9.1	8.4	9.4	9.1	6.6	8.4	7.0	7.5	9.1	9.5
1981	9.5	8.5	6.1	7.3	9.5	9.5	7.1	7.6	7.2	8.5	9.4	9.4
1982	8.5	7.4	8.5	7.3	8.5	8.5	7.1	6.3	8.1	7.5	7.5	8.1
1983	8.1	7.5	8.5	7.3	8.0	9.0	8.3	5.4	7.5	8.4	9.4	8.6
1984	9.2	9.3	8.5	10.0	7.6	8.4	8.6	8.5	7.4	9.3	9.2	8.4
1985	9.7	9.2	9	7	8.7	9.1	7.5	7.7	7.9	8.4	10	9.9
1986	10.2	8.8	9.1	7.5	9.2	6.7	7.7	7.8	8.5	8.6	10.2	9.5
1987	9.6	9.1	7.5	8.9	8.2	8.3	8.9	7	8.7	9.1	9.7	9.7
1988	8.9	9.4	9.4	7.5	9.6	8.4	4.9	7	7.4	8	10.5	9.8
1989	8.7	8.6	8.4	7.2	9.8	9.3	6.4	8.6	4.9	8.7	9.6	9
1990	9.4	6.4	8.3	8.6	9.9	9.5	7.4	6.9	7.8	9.2	9.8	9.7
1991	9.3	8.8	8.1	8.7	8.1	8.6	7	6.8	8.3	8.9	9.4	8.7
1992	6.8	6.3	9.3	8.4	9.2	8.6	7.1	5.6	7.6	8.8	8.9	8.6
1993	7.2	7.1	10.1	8.2	9.3	9.3	7.5	8.2	7.1	8.6	10	10
1994	10.2	9.7	8.8	8.4	9.2	8.1	7.1	7.4	8.1	9.6	8.5	9.7
1995	10.1	9.3	7.8	8.7	9.8	9.4	9.6	7.5	8.4	9.2	10.3	9.5
1996	9.2	10.4	8.4	9.1	9.6	8.9	8	9	8.1	9.5	9.4	10.1
1997	8.3	10.7	9.1	7.6	9.7	8.4	8.1	8	8.2	7.9	8.2	9.4
1998	6.9	8.2	8.5	9.9	9.4	9.5	7	7.3	7.7	8.7	10.3	10.5
1999	9.6	10.8	8.3	10.5	9.1	7.9	7.3	8.2	8.4	8.1	9.3	10.1
2000	10.2	10.3	9.9	8.4	8.9	9.9	7.8	8.6	7.4	8.1	10.4	9.7
2001	8.9	9.8	7.4	9.3	9.1	8.9	7.6	6.6	8.1	8.6	10.5	9
2002	8.9	9.2	7.9	9.1	9.2	8.7	8.1	6.8	7.5	9.1	10.1	9.3
2003	9	9.3	9.8	7.9	9.1	8.5	6.8	6.5	7.8	9.6	9.7	9.3
2004	8.9	10	8.6	8.3	9.9	8.5	7.9	8.1	7.6	8.4	9.8	8.6
2005	8.5	10.4	9.2	8.6	8.2	9.1	6.5	6.5	7.5	9.6	9.4	10.4
Mean (monthly)	**8.8**	**8.9**	**8.6**	**8.4**	**9.0**	**8.7**	**7.4**	**7.4**	**7.7**	**8.6**	**9.5**	**9.4**

Annex VI

Element: Mean Monthly Wind Speed (m/s)

Region: Shoa

Station: Metehara

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1976	1.8	2	2.6	2.1	2.6	4.2	3.2	3.5	2.4	2.1	1.8	1.8
1977	1.8	1.9	1.8	2.2	2.7	3.7	4.3	3	2.9	2	1.8	1.8
1978	1.9	1.5	1.5	2.2	3.5	4.5	3.6	2.6	2.3	2	1.8	1.9
1979	1.5	1.6	1.8	1.9	2	3.5	3.6	3	2.3	1.7	1.6	1.5
1980	1.5	1.7	2.3	2.5	2.4	3.8	3.9	3.6	2.7	2.1	1.7	1.9
1981	1.6	1.9	1.8	1.6	2.5	4	4.1	3.2	2.8	1.7	1.7	1.6
1982	1.5	1.7	1.7	1.8	2	3.5	3.6	4	1.8	1.5	1.4	1.4
1983	1.5	1.5	1.6	1.9	2.4	3.5	3.9	3.5	2.6	1.6	1.4	1.3
1984	1.3	1.4	1.8	1.8	0.7	1.2	1.1	3.5	0.5	0.8	0.7	0.7
1985	2.3	2.5	2.5	1.9	1.7	2.3	2.4	2.4	1.7	1.8	2.0	2.1
1986	1.7	2.3	1.9	2.4	2.2	3.0	2.7	2.5	2.0	2.0	2.3	2.5
1987	2.4	2.2	2.1	1.8	2.1	2.5	2.6	2.3	1.9	2.1	1.9	2.1
1988	2.0	2.1	2.2	2.0	2.0	2.8	3.0	1.9	1.4	1.5	1.6	1.9
1989	2.0	2.3	2.0	1.5	1.6	2.4	2.9	2.6	1.7	1.6	2.1	2.2
1990	2.3	1.8	1.6	1.4	1.8	2.6	2.6	2.4	1.7	1.6	1.9	1.8
1991	2.2	2.0	2.0	1.6	1.6	2.2	2.9	2.0	1.6	1.6	1.8	1.7
1992	2.0	2.1	2.4	1.9	1.5	2.0	2.4	2.0	1.5	1.3	1.5	1.8
1993	2.1	1.8	1.6	1.7	1.4	2.0	2.5	2.2	2.0	1.7	1.7	1.7
1994	1.6	2.0	2.2	1.8	1.8	2.6	x	1.7	1.4	1.5	1.5	1.7
1995	1.5	1.8	1.5	1.4	1.6	1.8	2.5	2.1	1.4	1.7	1.4	1.7
1996	1.7	1.7	1.8	1.4	1.4	2.4	2.2	2.0	1.5	1.4	1.3	1.3
1997	1.5	1.7	1.7	1.4	1.6	1.8	2.0	1.9	1.6	1.6	1.4	1.4
1998	1.6	1.7	1.6	1.6		2.3	2.3	1.8	1.3	1.1	1.5	1.4
1999	1.6	1.7	1.5	1.7	1.6	1.8	1.9	1.5	1.3	1.1	1.3	1.5
2000	1.6	1.7	1.9	1.7	1.5	2.2	2.2	1.8	1.3	1.0	1.3	1.3
2001	1.5	1.6	1.8	1.3	1.6	2.1	1.8	1.4	1.2	1.5	1.6	1.6
2002	1.8	2.3	1.6	1.7	1.5	2.0	2.1	1.9	1.3	1.5	1.5	1.8
2003	1.5	1.6	1.9	1.6	1.6	2.0	2.3	1.5	1.3	1.4	1.6	1.4
2004	1.5	1.7	1.4	1.1	1.2	1.8	3.0	1.7	1.3	1.4	1.5	1.6
2005	1.4	1.5	1.6	1.6	1.2	1.7	1.7	1.4	1.4	1.3	1.3	1.3
Mean (Monthly)	**1.74**	**1.84**	**1.86**	**1.75**	**1.84**	**2.61**	**2.73**	**2.36**	**1.74**	**1.57**	**1.60**	**1.66**

nnex VII: Information on the Satellite images Used

Land_Sat sensor Types	Path and Row	Date of Acquisition	Spatial Resolution (m)
Land sat-MSS	180_54	Jan.12, 1973	57 X 57
Land sat-TM	168_54	Jan.28 1986,	28.50 X 28.50
Land sat-ETM+	168_54	Jan.27, 2003	28.50 X 28.50
Panchromatic	168_54	Jan.27, 2003	14.25 X 14.25

Annex VIII: Surface Area of Lake Beseka in different times

Year	Area km^2	Source
1964	3.02	Arial photo.
1973	6.550862932	Landsat MSS
1986	31.55220486	Landsat TM
2003	43.49196368	Landsat ETM+

Annex IX: Mean monthly recordings of Lake Beseka Water level (m)

Month	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	Mean (monthly)
Jan		0.99	1.43	1.5	1.29	1.19	1.49	1.82	1.92	1.8	2.02	1.95	2.13	2.56
Feb.		1.07	1.44	1.57	1.29	1.17	1.46	1.84	1.9	1.66	2.03	2.04	2.13	2.58
Mar.		1.04	1.68	1.51	1.25	1.22	1.53	1.85	1.88	1.75	2.07	2.07	2.11	2.64
Apr.		1.07	1.59	1.45	1.2	1.39	1.58	1.86	1.84	1.8	2.04	2.14	2.09	2.66
May		1.21	1.54	1.39	1.16	1.38	1.61	1.86	1.8	1.89	2.01	2.11	2.06	2.66
Jun.		1.26	1.46	1.36	1.1	1.27	1.57	1.9	1.86	1.86	1.86	2.13	2.03	2.61
Jul.	0.47	1.33	1.47	1.38	1.18	1.25	1.5	1.87	1.89	1.92	2.08	2.1	2.07	2.57
Aug.	0.67	1.44	1.56	1.45	1.3	1.53	1.84	1.94	1.9	2.16	2.1	2.19	2.37	2.69
Sep.	0.81	1.45	1.58	1.45	1.38	1.65	1.93	1.98	1.92	2.23	2.08	2.25	2.45	2.74
Oct.	0.82	1.5	1.6	1.4	1.32	1.61	1.93	1.98	1.89	2.16	2.04	2.18	2.42	2.71
Nov.	0.88	1.55	1.56	1.34	1.24	1.52	1.88	1.95	1.85	2.07	1.98	2.13	2.28	2.66
Dec.	0.91	1.48	1.56	1.3	1.2	1.45	1.85	1.92	1.81	2.04	1.95	2.11	2.46	2.64
Mean (yearly)	0.76	1.28	1.54	1.43	1.24	1.39	1.68	1.90	1.87	1.95	2.02	2.12	2.22	2.60

Continued…

Months	1989	1990	1991	1992	1993	1994	1995	1996	2003	2004	2005	Mean (monthly)
Jan	2.24	2.39	2.63	2.82	3.01	3.19	3.34	3.54	5.14	5.45	5.56	2.56
Feb.	2.26	2.69	2.64	2.96	3.04	3.18	3.38	3.52	5.12	5.3	5.59	2.58
Mar.	2.27	2.92	2.66	2.94	3.04	3.17	3.5	3.53	5.8	5.27	5.58	2.64
Apr.	2.44	2.87	2.79	2.9	3.04	3.17	3.54	3.62	5.6	5.6	5.57	2.66
May	2.44	2.83	2.75	2.92	3.12	3.18	3.56	3.63	5.54	5.63	5.61	2.66
Jun.	2.41	2.71	2.74	2.89	3.13	3.17	3.52	3.51	5.12	5.57	5.61	2.61
Jul.	2.45	2.7	2.78	2.93	3.11	3.27	3.52	3.7	5.43	5.6	5.66	2.57
Aug.	2.51	2.82	2.9	2.98	3.08	3.39	3.63	3.82	5.46	5.72	5.80	2.69
Sep.	2.54	2.81	2.96	3.02	3.18	3.48	3.75	3.87	5.51	5.69	5.78	2.74
Oct.	2.43	2.72	2.9	3.03	3.19	3.45	3.69	3.82	5.49	5.82	5.66	2.71
Nov.	2.45	2.67	2.85	3.02	3.17	3.37	3.55	3.91	5.52	5.6	5.60	2.66
Dec.	2.39	2.63	2.82	3.06	3.06	3.36	3.5	3.9	5.42	5.55	5.55	2.64
Mean (yearly)	2.40	2.73	2.79	2.96	3.10	3.28	3.54	3.70	5.43	5.57	5.63	2.60

D E C L A R A T I O N

I here by declare that the thesis entitled "**Environmental Analysis of the Areal Expansion and Lake Level Rise of Lake Beseka, Main Ethiopian Rift**" has been carried out by me under the supervision of Dr. Asfawossen Asrat, Addis Ababa University, Addis Ababa during the year 2006/07 as a part of Masters of Science program in Geo-environmental Systems Analysis. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Fassika Abebe

Signature---------------------